

Proceedings of the Ninth TRB Conference on the Application of Transportation Planning Methods



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Proceedings of the Ninth TRB Conference on the Applications of Transportation Planning Methods

This volume contains papers and abstracts presented during the Ninth TRB Conference on the Application of Transportation Planning Methods, held at the Radisson Hotel and Conference Center in Baton Rouge, Louisiana, on April 6-10, 2003. The conference was organized and sponsored by the Transportation Planning Applications Committee (ADB50) of the Transportation Research Board, the Louisiana Transportation Research Center, the Louisiana Department of Transportation and Development, and the Louisiana Planning Council.

Jerry M. Faris of the Transportation Support Group served as Committee Chair. Jon Fricker of Purdue University served as Conference Chair. Eric Kalivoda of the Louisiana Department of Transportation and Development and Kirt Clement from the Louisiana Transportation Research Center served as local host co-chairs.

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Edited by Georgia Bennett and Rick Donnelly, March 2004.

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A Model of Journey Frequency

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Abstract. A new travel forecasting model set has been developed for the New York Metropolitan Transportation Council. This model set uses a microsimulation approach in which each individual trip in the region and the characteristics of that trip are estimated. Instead of modeling “trips” in the conventional sense, this model estimates “journeys”, defined as a sequence of movements having either home, work, or school at both ends.

This paper describes the journey frequency model, which is this model’s analog of the trip generation step. Every person and household in the 28-county New York region is modeled and the relevant characteristics of each person and household are estimated. These characteristics are used to determine the probability that each person will make a journey of a certain type on a typical weekday. Individuals are classified into one of three types: worker, non-working adult, and child (15 or younger). Household characteristics include the number of persons of each type, as well as the number of motor vehicles, income group, location, and accessibility. Trip types (purposes) include Work, School, University, Maintenance, Discretionary, and At Work.

The journeys and purposes are ordered according to their assumed priority to the household. The probability of a person making a certain number of a certain type of journey is conditioned upon other (more important) types of journeys that each person is estimated to make as well as the journeys that other household members are estimated to make. A separate model is developed for each person type and each trip type. The models use a basic multinomial logit function and were calibrated using a 10,000 sample home interview survey. This represents a more realistic representation of the impact of inter-household relationships on travel frequency than was previously possible.

The results indicated that the “usual” variables – HH size and income – have a substantial influence on journey frequency. But other variables, such as the type of person and the type of the other people in the household, the HH’s area type, and walk and transit accessibility also played a role. In addition, many of the conditional probabilities were statistically significant. For example, the probability of a non-working adult making a Maintenance journey was clearly influenced by whether or not there was a worker in the HH making a Work journey. This capability offers, for the first time, a much more comprehensive analysis and understanding of the variation in tripmaking among different households.

A new travel forecasting model set has been developed for the New York Metropolitan Transportation Council (NYMTC). This is the first regional synthetic travel demand model in this region in several decades. The New York Tri-State region (NY/NJ/CT) includes what is possibly the most complex set of travel choices in the country. NYMTC wanted a model that would not only replicate these choices as accurately as possible, but would represent the “best practice” in travel modeling as it currently exists.

In order to reflect these complex choices and to address the issue of trip chaining, a decision was made to estimate travel in terms of “journeys” rather than “trips”. A journey is a chain of one or more conventional trips with home, work, or school at both ends. Some consideration was given to modeling “tours”, which represent a more complete round-trip picture of travel (e.g., home-work-home). However, the additional complexity of tours made this approach infeasible within the context of this project. So, a “work” journey can be either home-to-work or work-to-home, regardless of the number of intermediate stops.

The decision to estimate journeys instead of trips then influences the definitions of the trip purposes. This model uses six trip purposes, or types: Work, School (K-12), University, Maintenance, Discretionary, and At Work. “Maintenance” involves those activities that are essential to maintaining the household. This includes weekly shopping, medical, serving passengers, most types of personal business (e.g., banking), and other activities that more or less have to be performed on a regular basis. “Discretionary” includes those activities that are more optional in nature, such as dining out, entertainment, visiting friends, recreation, etc. “At Work” basically describes all journeys that both start and end at the workplace.

A decision was made early in the model development to use a truly disaggregate, microsimulation approach. This means that the characteristics of *every* person, household, and journey in the New York region would be estimated. Not only does this represent the emerging best practice, as characterized by recent work in Portland and San Francisco, but also it is a very practical approach, given the size of this region and the amounts of data involved. The NYMTC modeled region includes 27 counties with a 1996 population of approximately 9 million. Using Census tract boundaries and previously defined zones, a system of 3,586 internal traffic analysis zones was developed. This creates trip matrices with almost 13 million cells. The diversity of transit services created a need to define numerous travel sub-markets within each zone, resulting in the potential to store and manipulate hundreds of millions of values, most of which would be tiny fractions, to describe a single scenario. In comparison, keeping track of some 60 million individual trips is relatively simple.

A conventional zone-based trip generation model estimates the number of trip productions and attractions in each zone. In the context of the NYMTC model, this function morphs into a “journey frequency model”. As noted above, this estimates travel in terms of weekday journeys, not simple trips. Also, instead of aggregate trip end totals, this model operates on individual person data to estimate the probability that each person makes a trip of a certain type. In application, these probabilities are used in a Monte Carlo simulation approach to convert those probabilities into a binary outcome: the person either makes the trip or doesn’t.

Journey probabilities are calculated for each person type and each trip type. The person types are: worker (age 16 or older, full- or part-time), non-working adult (age 16 or older), and child (age 15 or younger, assumed not to be employed). The utility functions include household characteristics: the number of persons of each type, as well as the number of motor vehicles, income group, location, and accessibility. The functions are also ordered according to a hierarchy based on the presumed relative importance of each trip purpose. The utility functions for less important journeys are conditioned on the results from the higher importance trips. For

example, the probability that a worker makes a Maintenance journey is affected by the probability that that same worker was previously estimated to make a Work journey. The calibration data was an extensive home interview survey of travel taken by the NYMTC in 1990 and 1991. This survey had approximately 10,000 household samples of weekday travel. The travel information was summarized by paired journeys, or tours, which include the home zone and non-home zone but which do not include stops between the origin and destination. For example, a person who on the way to work stopped to exercise and then to eat a meal and on the way home stopped to shop would have made one work paired journey. In the NYMTC model process, the stops are handled after the journeys have been distributed.

The travel for each household was reviewed to build the paired journey records. In the calibration file, each record, a paired journey, contained information on the purpose of the journey, the availability of transit, the other journeys the person made, the journeys the other members of the household made, and information about the household, such as the income level and the number of vehicles available. In addition, the record contained a measure of transit and walking accessibility. In this study, accessibility for an origin zone was defined as the employment divided by the square of the travel time for each interchange, summed for all destination zones. Care was taken to define the type of person. The person definition was working adult, non-working adult, and child (15 or younger). There were 13,826 adult workers, 7,419 adult non-workers, and 5,405 children in the calibration data set.

There were approximately 27,000 journey records in the calibration file. Of these journeys, over 17,000 were made by adult workers, approximately 5,000 by children, and about 4,500 by adult non-workers. The journey records were summarized for each individual in each surveyed household so that the actual number of journeys by type for each person was known. Information concerning the other attributes of the household and journeys made by other household members was attached to each record. ALOGIT software was used to estimate the models for journey frequency.

The basic idea of the model was that the microsimulation process would allow the determination of interaction among journeys by a person, and the interaction with journeys by other members of the household. In order to determine this interaction, it was first necessary to develop an “order”, or priority, of the journeys, by type of person and by purpose. The order was to be the most “important” purpose/person first, followed by the second, etc. The importance in this definition is if the making (or not making) of a journey affects the making (or not making) of subsequent journeys. For example, in a two person family consisting of a worker and a child, if the child does not go to school on a given day, perhaps the child is sick, and it is then logical to assume that the probability of the worker going to work would decrease. The researchers knew of no statistical method to determine what the optimum order of journeys “should” be. Instead, a specific order was assumed and during the analysis this order was revised as the analysis showed “connectivity” between purposes and persons. The final order of the model is as follows (listed in decreasing order of importance):

1. School Journeys by children
2. School Journeys by non-working adults (age 16 and over)
3. School Journeys by working adults (e.g., high school students with part time jobs)

4. University Journeys by non-working adults (by definition, children cannot make university Journeys)
5. University Journeys by working adults
6. Work Journeys by workers (obviously, children and non-working adults cannot make work Journeys)
7. Maintenance Journeys by non-working adults
8. At Work Journeys by workers (note: only workers who go to work can make At Work Journeys)
9. Maintenance Journeys by workers
10. Maintenance Journeys by children
11. Discretionary Journeys by non-working adults
12. Discretionary Journeys by workers
13. Discretionary Journeys by children

Given this ordering, the interrelations between persons and journeys can be analyzed using choice modeling techniques. The final interaction determined in this analysis is shown graphically in Figure 1. The choice modeling technique was multinomial logit and in all cases the utility for making no journeys is defined as zero. The probability of making 1, 2, 3 or more journeys was investigated prior to beginning the analysis and the number of choices was selected so that a sufficient number of journeys were in each choice. In some cases that meant that there were only two choices (no journeys and one or more journeys) and in other cases there were four choices (0, 1, 2, and 3+ journeys). The choice set for each model is shown in Tables 1 and 2.

Nested logit models were also investigated, but were not found to provide superior accuracy, improved explanatory power, or more logical coefficient values than the multinomial results. A typical nesting structure that was tested had the top level as: no journey vs. one or more journeys. Under the “1+” category, the choices are one journey vs. two or more journeys.

In application, the individual models are applied, in the above order, and the probabilities of making 0, 1, or more journeys is used in a Monte Carlo technique to determine how many journeys this person makes. These discrete journeys are then used as independent variables for the subsequent models. In application, the choices with the open-ended number of journeys (such as 1+) were given discrete probabilities for each observed choice (1, 2, 3) with the probabilities taken from the survey data. The base data probabilities for these “open ended” choices are shown in Tables 1 and 2.

There are nineteen choice utility functions developed as part of this journey frequency model. The coefficients for each of these functions are shown on Tables 1 and 3 and the abbreviations shown on these tables are defined in Table 5. All the independent variables used in the model were statistically significant and the Student’s t test values are shown in Tables 2 and 4. Tables 1 and 3 also present two other measures of model accuracy: 1) the “ ρ^2 ” value from ALOGIT and the “hit rate”, which estimates how well the model’s estimate of the discrete number of journeys matches the observed value. The linked journey frequency models were specified in the following sequence:

1. Journeys to school for children are modeled first, using fairly standard variables, such as income, number of children and urban area identifiers.

2. Journeys to school for workers and then non-workers are modeled, with having a child going to school being a Boolean indicator that has a positive impact on journey-making utilities. The other independent variables are fairly standard variables, such as income.
3. Journey to university for non-workers are modeled with no reference to any other journey making but with standard independent variables.
4. Journeys to university for workers are modeled having a child-at-home alone Boolean indicator that has a negative impact on journey-making utilities. The child-at-home variable is defined as 1 when a child in the household did not go to school and all the non-workers made a school or university journey.
5. Journeys to work are modeled using indicators for a child-at-home event and if the worker made a school journey (negative impact). Other independent variables are income, if the household is a 2 (or greater) worker household, and if there is more than 1 non-worker in the household.
6. Maintenance journeys for non-workers are modeled. This model is based on whether the non-worker made a school journey (negative impact) and whether a worker in the household did not go to work (negative impact). The model also uses a “car availability” Boolean indicator – which is positive (1) if there are more vehicles available to the household than there are workers. This vehicle availability has a strong positive impact. Finally, the model uses a walk accessibility measure. This measure is the sum of the employment divided by the square of the walk time for each destination (from the zone of the household). This measure has a positive impact.
7. Journeys at work are modeled for those workers that made a journey to work.
8. Maintenance journeys are modeled for workers having indicators for workers making School journeys and making Work journeys. A Boolean variable indicating if this is a multi-worker / no non-worker household is also used and this has a strong positive affect.
9. Maintenance journeys are modeled for children having indicators for School journeys made by the same child (this have a negative impact for journey-making utilities) as well as for Maintenance journeys made by adult household members – working and non-working (those have a positive impact on journey-making utilities reflecting intra-household co-operation in mutual journey-making).
10. Discretionary journeys are modeled for non-working adults. This model has a transit accessibility measure, computed the same as walk accessibility, except using transit travel time.
11. Discretionary journeys are modeled for workers. This model has Boolean indicators if a worker made a Work journey (negative impact), if any non-worker in the household made a Discretionary journey (positive impact), and if the worker made a Maintenance journey (positive impact).
12. Finally, Discretionary journeys are modeled for children. This model has Boolean indicators if the child made a school journey (negative impact), if the child made a Maintenance journey (negative impact), if any worker made a Discretionary journey (positive impact) and if any non-worker made a Discretionary journey (positive impact).

The Boolean indicators “linking” the journeys by a person and linking the journeys among persons are typically strong variables and probably represent, to some extent, limited travel time budgets (so workers who make Work journeys make fewer Discretionary and Maintenance journeys) and the linking of family trips. This linking of family trips may prove to be of considerable importance in mode choice modeling but this would require a more detailed distribution model.

This paper presents the development of a new model of journey frequency. This combines several concepts that are either new or are just beginning to find application in other “best practice” models. The definition of travel in terms of journeys instead of simple trips enables the subsequent development of true models of trip chaining behavior. Also, the use of journeys enables more robust mode choice and time of day models, in which the mode and time characteristics of all segments of the journey are linked.

The NYMTC model project also involved the development of demographic simulation models that can reliably synthesize the characteristics of persons and households for an entire region. This, in turn, makes possible the application of travel models on a microsimulation basis. This means that disaggregate, probabilistic models of individual behavior, which specifically consider not only the interaction between household members, but also the interaction of activities for each person, can be developed.

This analysis has confirmed that in general, journey frequency is based largely on the same demographic variables that have traditionally been considered in trip generation: household income and size. However, this work has been able to investigate factors that have previously not been considered in real world travel models. Most of the models responded better to the number of persons of certain type, rather than the total number of persons. The logit structure also made it possible to incorporate different types of size variables (presence of *any* children vs. number of children). This makes it possible to examine more detailed influences on household journey generation.

Vehicle availability was important in some models, but not all of them. Income group was more influential than vehicle availability, in general. Walk and transit accessibility were key variables in some of the equations. In this model, walk accessibility is basically a surrogate for density and largely serves to separate parts of Manhattan and other super-high density areas from the rest of the region. Of course, the high quality of transit service in the New York region would lead one to expect that transit accessibility would be an influential factor and it is.

But the most intriguing findings involve the influence of other journeys, both by the person whose travel is being estimated and by other persons in the household. For example, in the model of Maintenance journeys by workers, one of the most significant variables is whether or not this worker was also estimated to make a Work journey. In the model of Discretionary journeys by workers, a key variable is whether or not any non-working adult in the household was estimated to make a Discretionary journey.

The ability to consider such complex relationships clearly enhances the model’s representation of reality and should make the model more sensitive to future demographic changes. This should

help the model deal more effectively with trends such as the aging of the population, changing birth rates, and changing workforce participation rates. In addition the ordered model with the ability to link persons and journeys could be extended to distribution and mode choice models, in that family “group” journeys might be considered both in distribution and mode choice. Such an expansion of the modeling process would address many un-answered questions on the choice of mode, especially the use of group travel by private automobile.

The authors wish to acknowledge Tom Schulze of NYMTC and Bob Donnelly of Parsons, Brinckerhoff for their role in leading this project and for providing the vision to encourage the development of an advanced travel model. Appreciation is also due Peter Vovsha of Parsons, Brinckerhoff for his insightful advice and counsel and to Jeff Bruggeman of AECOM for his tireless work to implement the model.

FIGURE 1 - Interactions Among the Journey Frequency Models

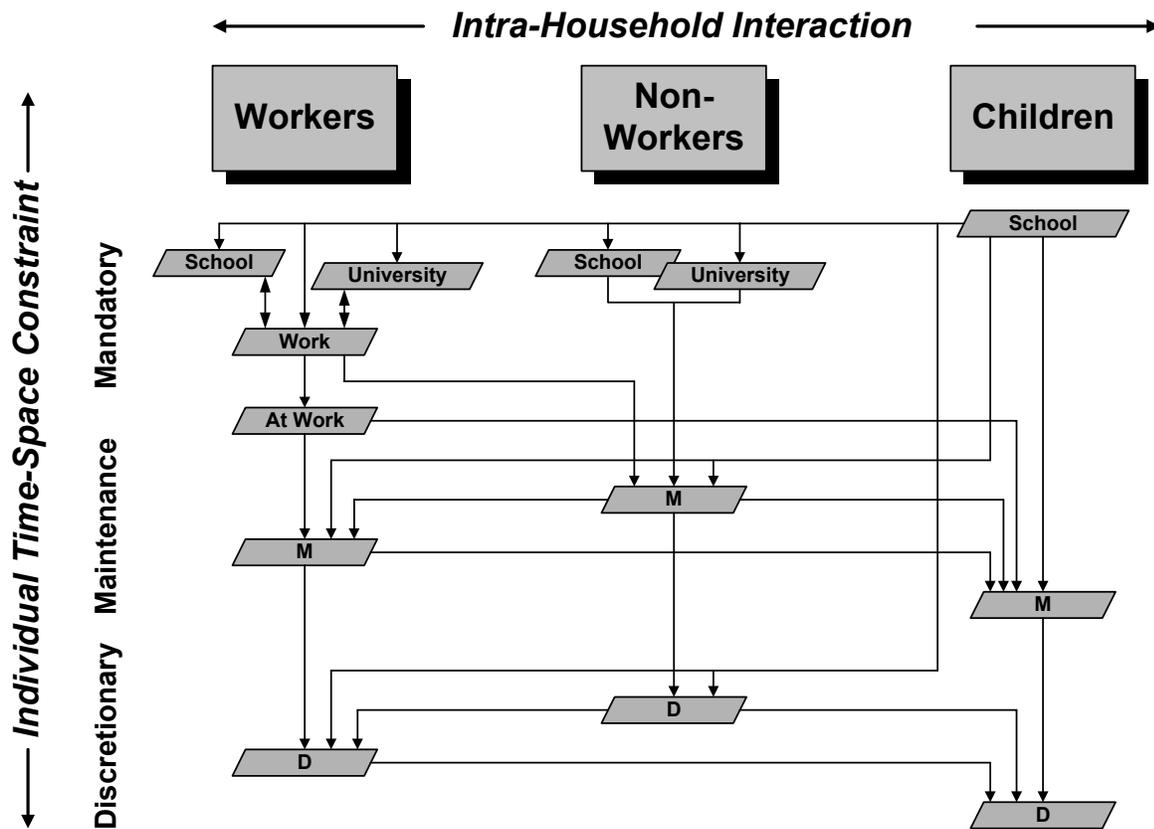


TABLE 1 - Coefficients for the School, University and Work Models

Variable	SCH / CHL Choice 1	SCH/NWA Choice 1	SCH/WKR Choice 1	UNI/NWA Choice 1	UNI/WKR Choice 1	WRK/WKR Choice 1	WRK/WKR Choice 2
Constant	0.43230	-3.87000	-5.84000	-4.51100	-4.60400	1.27700	-1.806
INC1			1.32900	0.25650	1.57800	-0.45660	-1.893
INC2	-0.23390	-0.49280					
INC3	-0.24450						
1+ NWA?	-0.33120			0.27990	0.36690	-0.25660	
1 WKR?				0.92040			
2+ WKR?				1.58600	0.78630	-0.10470	
CHL#	0.14650	-0.63520	-0.59450				
WKR#	0.09417	0.95530	0.69700				
Manhattan?	0.18730			1.07500			
Urban?	-0.59400		-0.95200	0.83210			
NWA#		0.42870					
Vehicles#		-0.18650					
CHL at Sch		2.08800	1.94700				
CHL home alone?					-1.12800	-0.56800	-0.8637
WKR make SCH J?						-2.09800	-2.961
Choices	0 and 1+	0 and 1+	0 and 1+	0 and 1+	0 and 1+	0, 1, 2+	
Prob choice 2	57.80%	7.80%	1.60%	4.10%	1.90%	69.00%	
Prob choice 3						3.50%	
1 Prob	98.02%	95.42%	95.78%	97.20%	93.30%	95.17%	
2+ Prob	1.98%	4.58%	4.22%	2.80%	6.70%		
2 Prob						3.30%	
3+ Prob						0.20%	
Rho Square	0.0432	0.6706	0.8911	0.7685	0.8693	0.3582	
Hit Rate	62%	92%	98%	97%	98%	70%	

TABLE 2 - Student t Values for the School, University and Work Models

Variable	SCH / CHL Choice 1	SCH/NWA Choice 1	SCH/WKR Choice 1	UNI/NWA Choice 1	UNI/WKR Choice 1	WRK/WKR Choice 1	WRK/WKR Choice 2
Constant	3.0	27.6	28.0	27.8	31.2	28.9	35.0
INC1			4.8	1.6	8.6	5.1	4.0
INC2	2.3	5.5					
INC3	2.3						
1+ NWA?	5.1			2.3	1.9	6.2	
1 WKR?				6.2	5.0		
2+ WKR?				9.6		2.4	
CHL#	5.5	7.7	4.6				
WKR#	2.1	18.7	10.3				
Manhattan?	1.6			5.1			
Urban?	10.2		4.5	6.4			
NWA#		8.6					
Vehicles#		4.9					
CHL at Sch		14.2	8.7				
CHL home alone?					3.9	9.9	5.1
WKR make SCH J?						19.6	4.8

TABLE 3 - Coefficients for Maintenance, At Work, and Discretionary Models

Variable	MAI/NWA Choice 1	MAI/NWA Choice 2	MAI/NWA Choice 3	ATW/WKR Choice 1	MAI/WKR Choice 1	MAI/WKR Choice 2	MAI/WKR Choice 3	MAI/CHL Choice 1	MAI / CHL Choice 2	DIS/?NWA Choice 1	DIS/WKR Choice 1	DIS/CHL Choice 1
Constant	-0.51380	-1.68000	-3.70900	-1.07000	-1.24700	-2.51400	-3.58200	1.71300	-2.94500	-1.62600	-2.22300	-1.14300
INC1				-1.99600						-0.38820		
INC2				-0.36300						-0.22500		
1+ NWA?				-0.44250								-0.48080
2+ NWA?	-0.10490	-0.43370	-0.52530							-0.26730		
1 WKR?										-0.23470		
2+ WKR?				-0.46490								
2+ WKR & 0 NWA?					0.12120	0.18890					0.35090	
1+ CHL?		0.70600	1.39300	-0.18700	0.28160	0.74150	1.29200					
Manhattan?				0.44820								
Urban?								-0.16580	-0.29420			
Suburban?			0.52220		0.10130	0.65480	0.94140					-0.79340
CHL make SCH J?								-1.38900	-2.78400			-1.17800
CHL make MAI J?												-0.81110
WKR make SCH J?					-0.53590	-0.16530	-1.51400					
WKR not WRK?	-0.26350	-0.38800	-0.79040									
WKR make WRK J?					-0.50890	-1.55700	-2.30100				-0.51800	
WKR make MAI J?								1.45600	1.56600		0.27910	
Any WKR make DIS J?												1.94900
NWA make SCH J	-1.10800	-2.04600	-3.51100									
NWA make MAI J								1.41500	2.11900			
Any NWA make DIS J?											1.16200	
Any NWA make MAI J?												0.98660
Car Available	0.53036	0.82060	1.65400	0.28770						0.48200		
Walk Accessibility	0.2359* 10 ⁻³	0.2359* 10 ⁻³	0.7304* 10 ⁻³									
Transit Accessibility										0.5515*10 ⁻⁴		
Choices	0, 1, 2, 3+			0, 1+	0, 1, 2, 3+			0, 1, 2+			0, 1+	0, 1+
Prob choice 2	32.10%			15.30%	18.40%			19.80%			9.90%	15.90%
Prob choice 3	12.40%				5.20%			6.00%				
Prob choice 4	5.30%				2.10%							
1 Prob	64.46%			91.08%	71.60%			76.74%			92.99%	90.57%
2+ Prob				8.92%							7.01%	9.43%
2 Prob	24.90%				20.23%			18.86%				
3+ Prob								4.40%				
3 Prob	7.95%				6.10%							
4+ Prob	2.69%				2.07%							
Rho Square	0.2340			0.4033	0.4736			0.4590			0.5467	0.4535
Hit Rate	33%			84%	74%			75%			91%	83%

TABLE 4 - Student's t values for Maintenance, At Work, and Discretionary Journeys

Variable	MAI/NWA Choice 1	MAI/NWA Choice 2	MAI/NWA Choice 3	ATW/WKR Choice 1	MAI/WKR Choice 1	MAI/WKR Choice 2	MAI/WKR Choice 3	MAI/CHL Choice 1	MAI / CHL Choice 2	DIS/?NWA Choice 1	DIS/WKR Choice 1	DIS/CHL Choice 1
Constant	9.9	21.5	22.5	12.7	22.7	26.5	23.9	24.1	24.3	12.7	33.7	14.5
INC1				6.9						2.9		
INC2				6.0						3.0		
1+ NWA?				6.4								4.4
2+ NWA?	2.0	5.8	4.7	6.9						3.9		
1 WKR?										3.2		
2+ WKR?												
2+ WKR & 0 NWA?					2.7	2.4					5.6	
1+ CHL?		9.7	13.0	3.1	6.2	9.3	9.9					
Manhattan?				4.8								
Urban?								2.2	2.4			
Suburban?			4.3		2.2	7.7	6.8					8.8
CHL make SCH J?								19.4	18.9			14.5
CHL make MAI J?												8.6
WKR make SCH J?					4.1	5.5	3.9					
WKR not WRK?	3.9	4.0	5.0									
WKR make WRK J?					10.2	19.4	17.4				8.5	
WKR make MAI J?								20.0	13.2		4.4	
Any WKR make DIS J?												22.6
NWA make SCH J	12.2	10.4	6.0									
NWA make MAI J								19.6	17.6			
Any NWA make DIS J?											11.8	8.5
Any NWA make MAI J?												
Car Available	9.1	10.6	11.8	4.0						5.8		
Walk Accessibility	2.4	2.4	3.4									
Transit Accessibility										2.1		

Table 5 - Abbreviations Used

WKR	working adult (full- or part-time, age 16 or older)
NWA	non-working adult (age 16 or older)
CHL	child (age 15 or younger, assumed not to be employed)
HH	household
WRK	work journey pair (tour)
SCH	school journey pair
UNI	university journey pair
MAI	maintenance journey pair
DIS	discretionary journey pair
ATW	at-work journey pair (begins and ends at work)

Independent Variable Definitions

Dummy (Boolean) variables are identified as "?". The dummy variable is 1 if the condition is true, otherwise 0.

1+ CHL?	Are there any children in this HH?
1+ NWA?	Are there any NWAs in this HH?
1+ WKR?	Are there any workers in this HH?
1 WKR?	Is there exactly one worker in this HH?
2+ NWA?	Are there two or more NWAs in this HH?
2+ WKR?	Are there two or more workers in this HH?
2+ WKR & 0 NWA?	Are there two or more workers in this HH <u>and</u> no NWAs?
A WKR not at WRK?	This is a HH with more workers than paired work journeys, implying that at least one of the workers didn't go to work.
Any NWA make DIS J?	Did any NWA in this HH make a discretionary journey?
Any WKR make DIS J?	Did any worker in this HH make a discretionary journey?
Car available?	Is there possibly a vehicle available to this NWA? That is, is the number of vehicles greater than the number of workers?
CHL	Number of children in this HH
CHL at SCH?	Did <u>any</u> child in this HH go to school?
CHL home alone?	Is there possibly a child home alone? This is a HH with at least one child <u>and</u> more children than paired SCH journeys by children <u>and</u> the number of NWAs, less the number of paired UNI journeys by NWAs, less the number of paired SCH journeys by NWAs is less than or equal to zero.
CHL make MAI J?	Did this child make a maintenance journey?
CHL make SCH J?	Did this child make a school journey?
Income 1?	Is this HH in income group 1? (lowest 15% of income)
Income 2?	Is this HH in income group 2? (between 16 and 84% of income)
Income 3?	Is this HH in income group 3? (highest 15% of income)
Manhattan?	Is this HH located in Manhattan?
Suburban?	Is the HH located in a Suburban county?
Urban?	Is the HH located in an Urban county?
NWA make MAI J?	Did this NWA make a maintenance journey?
NWA make SCH J?	Did this NWA make a school journey?
Vehicles	Number of vehicles in this HH
WKR	Number of workers in this HH
WKR make MAI J?	Did this worker make a maintenance journey?
WKR make SCH J?	Did this worker make a school journey?
WKR make WRK J?	Did this worker make a work journey?

Accessibility

“Accessibility” for zone *i* is defined for a mode as the sum of: total employment / *i-j* travel time by mode², summed across all destination zones. For transit, “travel time” includes walk, wait, and in-vehicle time and is defined only for the walk-access path. If the HH is not within 0.5 mi of a transit stop the transit accessibility is set to zero.

Implementation of a Tour-based Microsimulation Regional Travel Demand Model

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Abstract. The Mid-Ohio Regional Planning Commission (MORPC) has undertaken a project to develop a new set of travel demand models for the central Ohio region. This project combined the travel demand models from two Metropolitan Planning Organizations (MPO), MORPC and the Licking County Transportation Study (LCATS).

In an effort to update the data needed to develop a new set of travel demand models for the region, MORPC and LCATS conducted a household survey in 1999. In the fall of 2001, MORPC started the effort of building a new set of best practice travel forecasting models. Compared to the previous modeling system, and conventional models in general, the new modeling system features a tour-based approach (as opposed to a trip-based approach) that is implemented using the microsimulation of individual (as opposed to aggregate) activity and travel choices.

The principal components of the new model have been estimated with the household survey data as logit discrete choice probability models, and are applied with microsimulation. They include the following principal modules: 1) the Household-Auto Ownership-Daily Activity-Tour (HADT) model, 2) a Tour Mode-Destination Choice Model, with an Attraction Sub-model, and 3) a Sub-Tour/Trip Mode and Secondary Stops model. A particularly innovative aspect of the new MORPC modeling approach is the determination of Joint-Household Travel early in the model stream, explicitly accounting for joint travel between household members in the tour production stage. All highway and transit network processing is done within TP+.

Challenges to the development of this model include the coordination between the two MPOs and the reconciliation of the data needed for estimation, which was collected over eight years. MPO coordination efforts include the potential need to accommodate two different sets of socio-economic data and the need for the smaller MPO to be able to run analyses for a sub-set of the model.

This paper discusses both the challenges and advantages of developing a tour-based microsimulation model set, the details of the different components and a case study showing the results of the model.

In 2001, the Mid-Ohio Regional Planning Commission (MORPC), the MPO for Columbus, Ohio, undertook a study to develop a new set of regional travel demand forecasting models. The Licking County Area Transportation Study (LCATS), the MPO for Newark/Heath, Ohio, directly to the east of the MORPC area, also agreed to participate in the new modeling initiative. The set of travel demand models that have been developed in this project represent the latest in the series of new metropolitan

models for transportation planning that feature the emerging best practice approach of tour-based modeling, applied within the framework of microsimulation. Following the first generation of its predecessor tour-based models in Portland, San Francisco, and New York, the new model set developed by PB Consult for the Mid-Ohio region is expected to demonstrate both the advantages of this modeling technology as well as its practicality for typical mid-size and large metropolitan areas. The models also include several important innovations that microsimulation makes possible, including the explicit modeling of joint travel by members of the household.

Background

The Columbus Regional Travel Demand Models were first designed in the mid-1960s and completed in 1970. The three-step model was moved into TRANPLAN in 1992, and has been maintained in that software since that time. In 1993, a transit on-board survey was conducted and used to develop mode-choice models for HBW-peak, HBW-non-peak, HBO, and NHB. These models were built to include HOV and tolls capabilities, although no such facilities exist in the area. A traditional three-step model (no mode choice) was developed separately for LCATS in 1999 in TRANPLAN. Both LCATS and MORPC began using Viper for highway network editing in 1999.

Several important transportation data development efforts were undertaken to support new models for the region. In 1995, the Ohio Department of Transportation (ODOT) conducted an external cordon roadside origin-destination survey. This survey was conducted at the boundaries of the original MORPC modeling area, the unofficial MORPC modeling area to the north, and the LCATS area. A map is included in Figure 1 that illustrates the different geographical areas that comprise the regional model area. In an effort to further develop the type of data needed to develop a new set of travel demand models for the region, MORPC and LCATS conducted a major household transportation survey in 1999. This survey collected data from a sample of 5,555 households, obtaining current demographic and detailed travel behavior data from residents of the region.

Because the official air-quality maintenance area for the region encompasses a three-county area, including the current modeling areas for both MPOs, and significant growth at the edge of the current modeling area, it was decided to expand the modeling area to include three entire counties, and parts of four other counties. This expansion includes areas that the external and household surveys did not cover.

In 2001, MORPC hired PB Consult to lead the development of a new set of travel demand models for the expanded area, making use of the recently collected travel data.

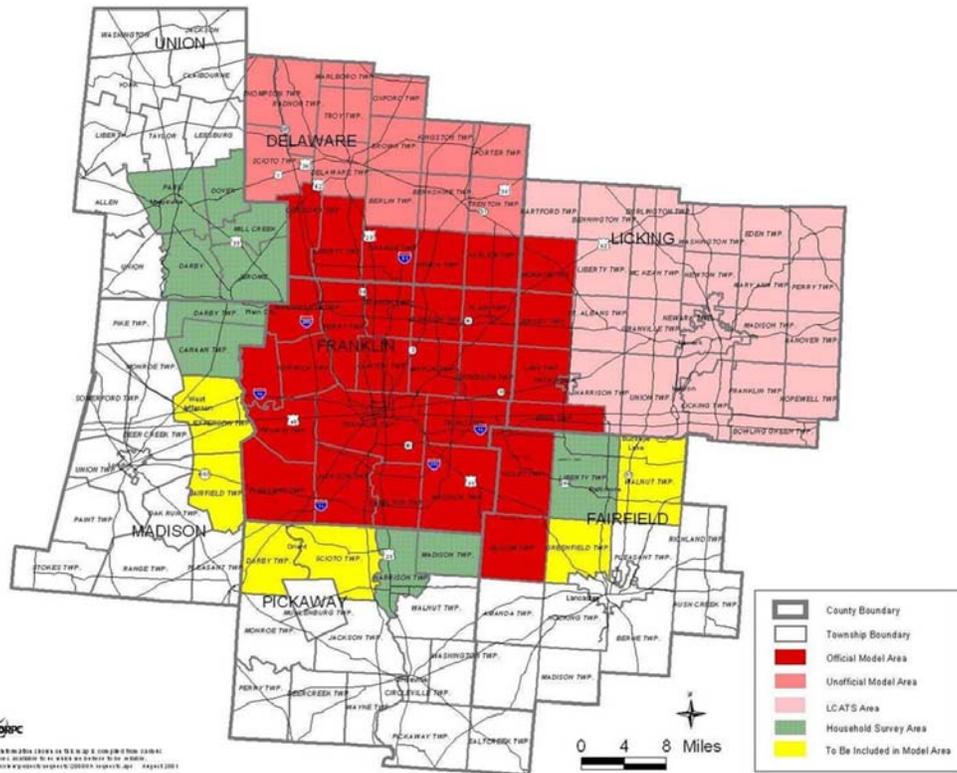


Figure 1 - MORPC and LCATS Planning Areas and Expanded Regional Model Area

Decision to Develop Tour-based/Microsimulation Models

Tour-based Approach: As part of the initial project workshop held in November 2001, PB Consult presented to the project advisory committee the concept of the tour-based microsimulation model. It was indicated that the tour-based approach allows for a more realistic simulation of trip-chaining and related travel patterns than conventional trip-based models. Tour-based models would essentially first link the home and primary destination of each entire tour as the unit of analysis, and then estimate secondary stops made on either the ‘to’ or ‘from’ legs of the tour. For example, the work destination of a worker is determined, and then the decision is modeled to make stops for other purposes on either or both legs of the tour. This tour is classified as a home-to-work tour, even if multiple stops are made to or from the work place. In the traditional four-step conventional trip-based model, if a stop were made on part of the commute, four trips would result: two Home-based Other (HBO), and two Non-Home based (NHB) trips. The trip-based classification completely loses the home-to-work connection, and therefore is likely to poorly represent the locational and mode choices made as part of this basic home-to-work commute activity.

Microsimulation of Choices: The other important new component of the proposed approach was the microsimulation of households, persons, and travel choices. As in a conventional model, certain socioeconomic data would be developed for each Traffic

Analysis Zone (TAZ) as inputs, such as total households, total population, average household income, and others. Rather than creating zone-based tables of market segmented aggregate data, the models would convert these projections to simulated populations represented by individual records, each representing a person and their household, and indicating their specific demographic attributes -- e.g., low, moderate, or high income; full-time employed, part-time, student, etc. At that time, a record could be drawn from the Public Use Micro Sample (PUMS) for that specific household located in its PUMA. At that point, a great deal of information is “known” about that household, including the number of children, ethnicity, and education level. These “uncontrolled” attributes could then be used in the rest of the model chain, or used for more complete reporting about the characteristics of population of users and non-users affected by modeled transportation projects or policies.

Variability of Microsimulation: One of the effects of the incorporation of microsimulation in travel demand models is the introduction of variability in results as part of the realization of probability-based choices, using Monte Carlo simulation. If the “seed” in the random number series used in application of this technique is not kept constant, the model will produce different results every time it is run, generally small differences for aggregate statistics such as changes in regional or sub-area VMT, but significantly different for, say, individual link volumes. Over the course of several runs, an average can be computed, as well as the statistics of variance that describe the overall variability.

The advisory committee was receptive to the obvious advantages offered by tour-based microsimulation travel demand models over aggregate trip-based models. In addition, the potential drawbacks associated with microsimulation variability were not seen as a serious problem. The committee was very receptive to the development of this type of model, which explicitly describes a source of errors associated with travel demand models, as opposed to the incorporation of the errors into the individual models and variables. While the modeling community implicitly knows that errors are generated with each model step and that a “typical weekday” will rarely, if ever, occur, this type of model can give a range of expected values, which can be very useful in reporting and analysis. The committee decided to implement the tour-based microsimulation approach in December 2001 with encouragement by U.S. DOT members of the panel.

Detailed specifications for the new modeling chain were then developed for the MORPC/LCATS model. New models were estimated using the household survey and other local data, with custom application programs developed in an Object-Oriented Programming approach by PB Consult. The principal components of the new model have been estimated as discrete choice logit probability models, with microsimulation realization. They include the following principal modules: 1) the Household Synthesis/Auto Ownership/Daily Activity/Tour Production model, 2) an Entire Tour Mode/Time of day/Destination Choice model, and 3) a Sub-Tour/Secondary Stops and Trip Mode Choice model. A flow chart that depicts the full MORPC modeling chain is shown in Figure 2.

Household Synthesis/Auto Ownership/Daily Activity Agenda/Tour Production

The first of the new MORPC model components is a series of models that generates each household, simulates the composition of the household, determines the number of vehicles available, and what the dominant daily activity “agenda” will be for each household member. Finally, a generation step is made to produce each individual’s mandatory tours for the day, the non-mandatory tours made jointly by members of the household, and then all other individual tours.

Household/Person Synthesis: The socioeconomic inputs to this model are comprised of twenty different zonal variables and are maintained for each TAZ in the modeling area. The distribution of the number of households of each size and income category is known from the data taken from the 2000 Census. For the base year of 2000, the household synthesis model generates the exact number of household records, each representing a household of 1, 2, 3, 4, or 5+ size. If a household has a size of 5+, then a second procedure determines the exact number of persons in that household. The household model also determines if that household has a low, moderate or high household income. Then the model determines what type of person each household member is: adult full-time worker, adult part-time worker, adult non-worker, adult university student, child student aged 16+ years, child student aged 6-15 years, or a child aged 0-5 years.

Auto-Availability: The next component of the first core model determines the number of vehicles available to the household. The main explanatory variables for the auto ownership model include the household size and composition, household income group, density-based area type, the transit accessibility of the TAZ, and the household’s “car sufficiency” rating, which is the relationship between the number of workers and the number of vehicles available. A Parking Model is also run at this stage to determine if each person would have a free parking space in the CBD, or if he would be required to use a paid parking space.

Daily Activity Agenda: At this point, the Daily Activity Agenda model is applied for each person in the household. Each person’s daily general travel pattern is categorized as either having a mandatory activity (work, university, or school), a non-mandatory activity, or no travel (stay at home or away from home). If the person is determined to have a mandatory activity, then the model determines the number of mandatory tours the person executes throughout the course of the day, allowing for up to three mandatory tours, as was determined a reasonable maximum based on the household survey. If a non-mandatory daily activity pattern was chosen, the model determines whether that person made 1, 2, 3, or 4+ such tours. Figure 3 shows the overall structure of the daily activity agenda model.

Ordered Tour Production: A hierarchy of tours is used to implement an ordered generation of tours across household members. In general, the relatively “individual” person categories take precedence and affect the subsequent choices of the more “dependent” person categories. Thus, the activity pattern of person categories lower in the hierarchical chain is based partially on the activities of those preceding it. For

example, if a child aged 0-5 has a stay-at-home activity agenda, then the probability of an adult having a stay-at-home activity pattern is higher than if the child's agenda were a school pattern.

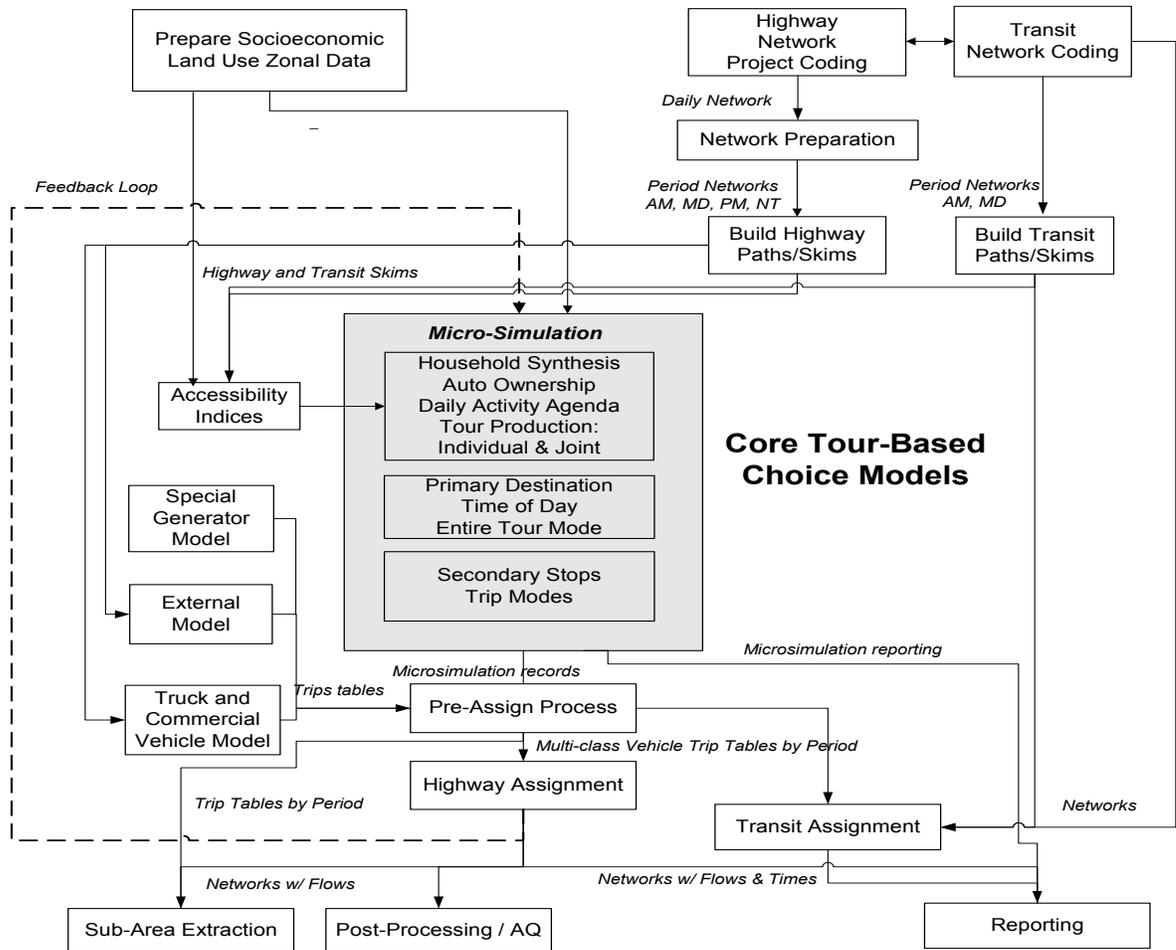
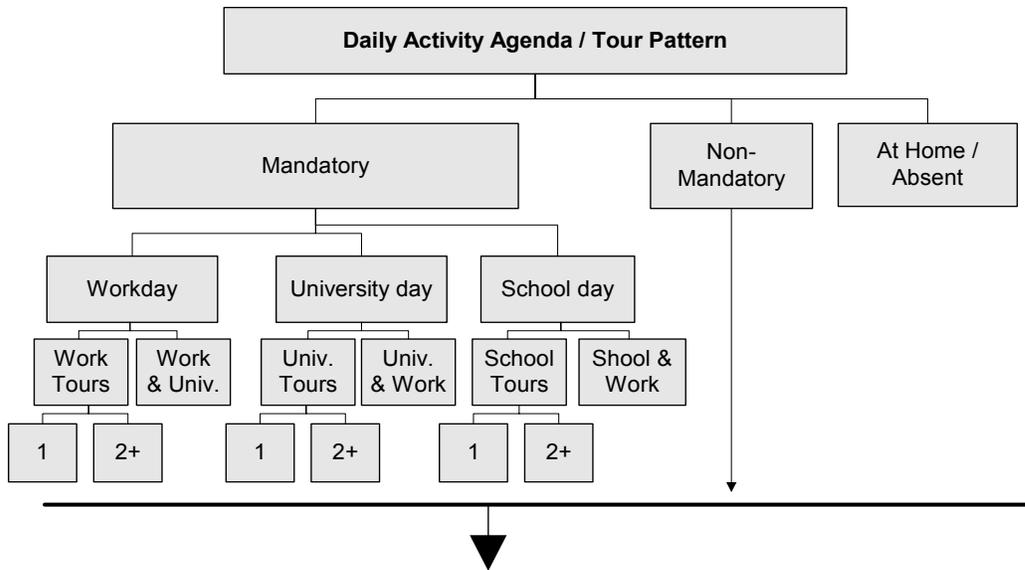


Figure 2 - MORPC Tour-Based/Microsimulation Models – General Applications Flow



Subsequent modeling of the exact number of non-mandatory individual and joint tours

Figure 3 - Classification of Daily Activity Patterns

The following hierarchy was adopted for the ordering by individual person types of the modeling procedures that determine the daily activity patterns in the household:

1. Child aged 0-5
2. School child aged 6-15
3. School child of driving age (16-17)
4. University student
5. Full-time working adult
6. Part-time working adult
7. Non-working adult

Time-of-Day Windows: Once the number of mandatory tours has been set, they are each scheduled within an “available time window.” There are five time periods within the model used for this purpose:

- Early Morning (4:00 AM – 6:30 AM)
- AM Peak (6:30 AM – 9:30 AM)
- Midday (9:30 AM – 3:30 PM)
- PM Peak (3:30 PM – 6:30 PM)
- Evening/Night (6:30 PM – 4:00 AM)

The concept of accounting for the “available time windows” for the tours made by each person in the household is an important element of the models, and one which is only possible in a microsimulation approach. Each time a tour is scheduled, the available time window for that person is reduced by the time required to make that tour. The time needed for each tour includes the duration time for the activity that defines the tour, and the time required to travel to and from the primary destination for the activity. After a tour is scheduled, the available time window is adjusted, and the next mandatory tour is scheduled conditioned on the revised temporal account for that individual.

Explicit Modeling of Joint Household Travel: One of the most significant innovations of

the new MORPC models is the manner in which travel made jointly by members of the household is addressed. A substantial portion of regional travel can be shown to be implemented by household members who travel together, primarily to participate in a shared household activity. This phenomenon of joint household travel, however, is not explicitly accounted for in most current regional travel models where the unit of travel (either trip or tour) is considered for each person separately at each stage of the modeling process. The MORPC models explicitly account for joint travel between household members at the tour-production stage, which is where these household decisions are made, and not at a subsequent mode choice step. After all mandatory tours are scheduled, the model calculates the overlap of the remaining available time windows between household members, and “synchronization indices,” or the possibility that household members can travel jointly for part of the trip (i.e., pick-ups or drop-offs). Joint tours are then generated by travel purpose and joint category (fully joint tours, joint half-tours, pick-ups and drop-offs). Joint tours are subsequently processed as a single unit for the remainder of the model. This ensures that a fully joint tour has the same destination for all participants, and that the driver in a half-joint tour has a secondary stop location at the primary destination of the passenger. Figure 4 shows the general modeling hierarchy for the joint household travel model components, comprised of three sequentially applied sub-models.

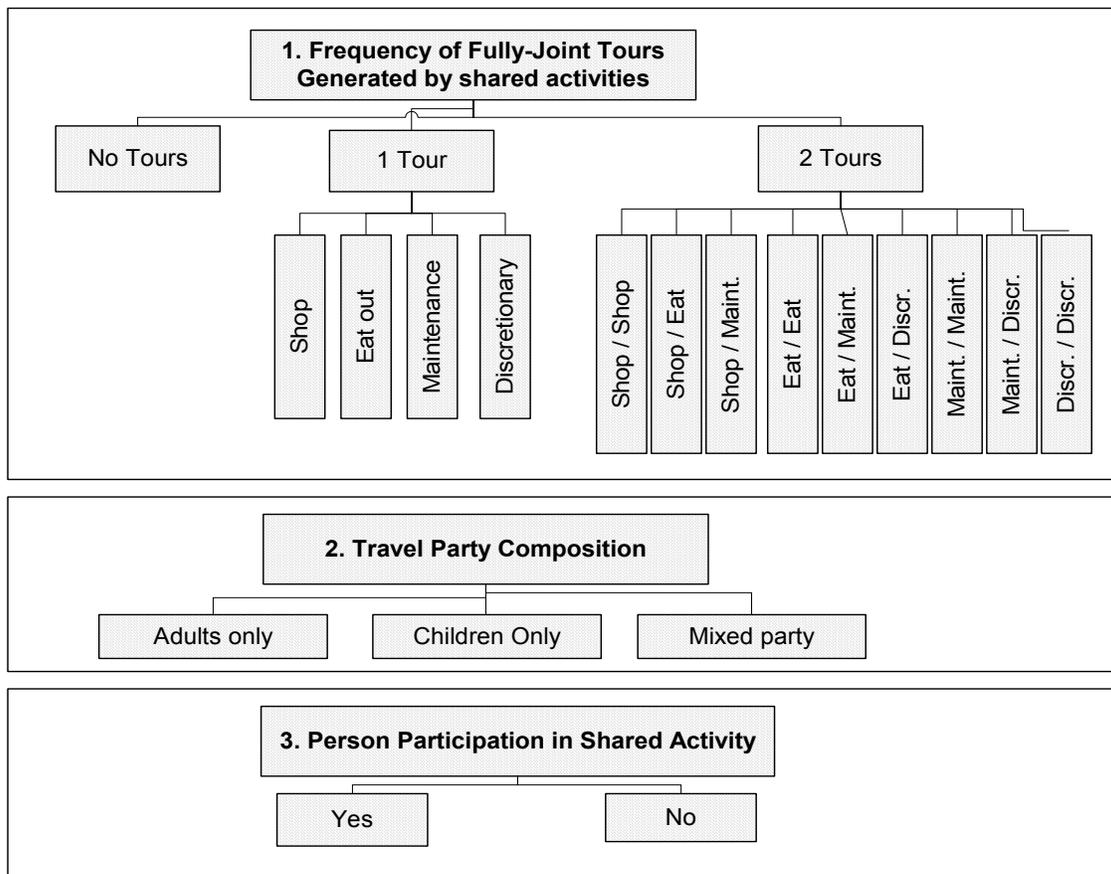


Figure 4 - Joint Travel in the Modeling Hierarchy

After all mandatory tours and joint tours have been scheduled for a household, the tour generation model determines if any non-mandatory tours are to be scheduled. This process takes into account the remaining available time windows and the number of joint tours already scheduled. All joint tours and non-mandatory tours are then scheduled in the remaining available time windows.

The end result of this first set of core models is a file with all the tour records for each simulated resident of the regional model area. In addition to the activity purpose or type of tour, each tour record carries the socioeconomic attributes of this person's household, such as the number of vehicles available to the household, the type of person and any associated data, his main daily activity pattern including time windows for those tours, and whether he has free parking in the CBD. For the base year MORPC model implementation, there are about 1.6 million individual tour records in this output file. This file becomes the input data used in the subsequent Entire Tour Mode/Destination/Time-of-Day Choice model.

Entire Tour Mode/Destination and Time-of-Day Choice Model

Like the first set of core models, the Entire Tour Mode/Destination/and Time-of-Day Choice are realized with Monte Carlo realization. An attraction sub-model generates the attractions or "size variables" used in the Destination Choice model. The Attraction model is mostly based on the land use data and employs a variety of relatively simple models to generate attractions for each tour purpose. The work attractions are stratified by low, moderate or high-income jobs. These models are similar to those found in most conventional four-step models.

After the attractions are generated for each TAZ, the Destination Choice Model determines the primary destination TAZ for the entire tour, using the estimated attractions in either a fully constrained method, such as for work tours, or as size variables when used with applying "relaxed constraints" in this distribution step, as is done for discretionary tours. The primary destination of a tour is determined by the utility of a destination TAZ. The destination model utilizes the estimated LogSum from the logit equations from the tour mode choice model and incorporates the attractiveness of the TAZ from the attractions model. Furthermore, the destination choice set is limited for each tour based on the allotted entire tour time. If one hour is allotted for a tour, then all destinations more than 30 minutes away are excluded from the choice set, as the tour time includes the travel time in both directions.

It is expected that the destination choice model will give better results in the central Ohio region than the traditional Gravity Model because of the multiple activity centers within the seven-county area. It is also expected that the stratification of jobs by income level will yield more accurate travel patterns.

The entire tour mode choice model is also a nested logit-based fractional probability model, with microsimulation to determine discrete outcomes for each tour record once the "production" (home) and the "attraction" (primary destination) are determined. Like

the other core choice models, the MORPC mode choice model was estimated using the Household Travel behavior data, but was supplemented with information from the On-Board because of the small number of observed transit riders in the household data. The mode choice model includes nests for new transit modes to be evaluated in planning studies with the MORPC model that do not exist today, including Light-Rail Transit (LRT), Busway Transit, and Commuter Rail. The nested logit model for the MORPC/LCATS entire tour mode choice model is structured as shown in Figure 5.

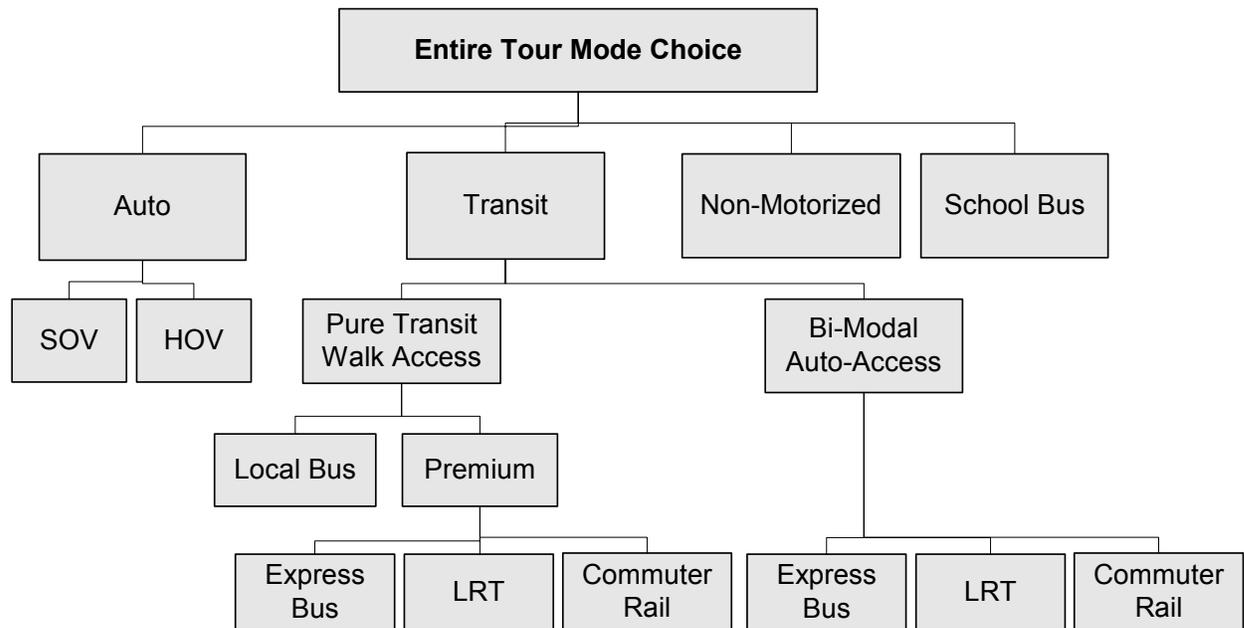


Figure 5 - MORPC Mode Choice Model – Nested Logit Structure

Secondary Stops Model and Sub-Tour/Trip Mode Choice Model

This component of the core models is run after each tour’s primary activity is linked with a destination and primary tour mode. There are two main components of this module: the determination and location of any stops on the tour, and the determination of any sub-tours from the primary destination of the main tour and their mode.

Using probabilities from the household survey, this model determines for each tour whether a stop is made on the in-bound or out-bound direction. If a stop is made in either direction, the trip purpose is determined and the destination TAZ is chosen. Based on the Household Travel survey, more stops are made during the return leg (to home) of the tour, than on the outbound leg. If a stop is made on one leg of the tour, the model determines whether a second stop is made on the other leg. Once the frequency or the number of stops is determined for each tour, the location is determined based on the concept of route deviation and the density of opportunities. Data from the household survey did not support the need to model a second stop on either the out-bound or the in-bound direction. Obviously, joint household travel is accounted for in this step, with the majority of the stops having the escorting purpose. With the stop pattern determined, and the entire tour mode established in the prior model, a final “trip” mode is determined for

each travel segment on the tour, where each trip's origin and destinations have been defined by either the location of the home, stops, or primary destination.

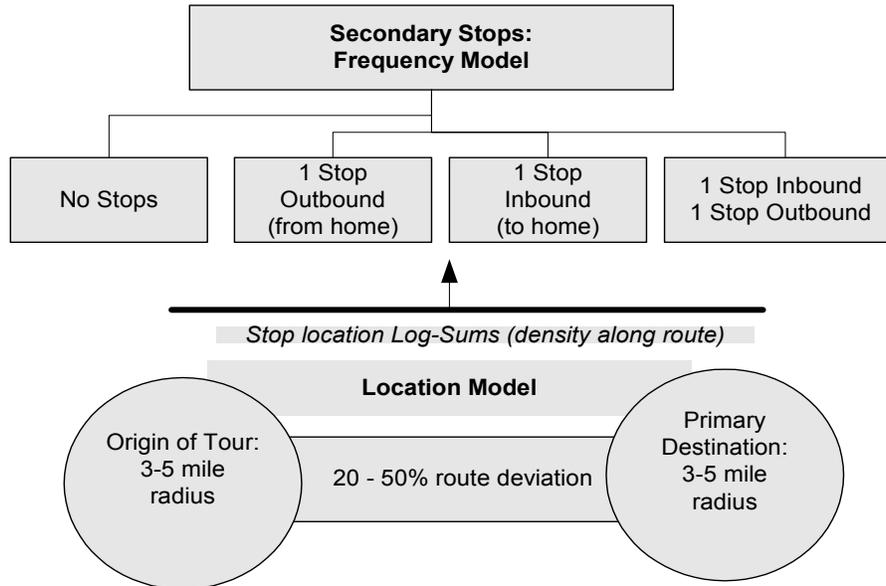


Figure 6 - MORPC Secondary Stops and Trip Mode Models

While at a primary destination, a person can make a sub-tour, or a tour with the origin and destination at the tour destination end. The majority of these tours are made of travel from work to eat out or for business purposes. Data from the household survey supported the inclusion of one sub-tour. The incidence of two or more sub-tours in the survey was extremely low. After the destination of the sub-tour is chosen, the mode needs to be chosen for the sub-tour. The available modes for the sub-tour are dependent on the primary tour mode. If a person chose transit as his primary tour mode, then SOV is not an allowable mode for the sub-tour. The destination and mode choice for both of these models are implemented with the logit models described above.

Other Models

Several other models exist to support the main set of models. A Parking Model was developed to link the actual vehicle destination to the work location in the CBD. Trip ends for these trips would then be reassigned from the actual work location TAZ to the parking TAZ. Parking spaces are stratified by free and paid parking spaces, and by short and long term. If a person is determined to be a free parker, then only the free spaces are available to him. Likewise, if the person is determined to be a paying parker, only the paid spaces were available for that trip.

A Commercial Vehicle Model (CVM) has been developed for the regional model as well. The only commercial vehicle data available was from the external cordon survey. Therefore the data from the Internal-External trips, in particular the trip length frequencies, were used to estimate the I-E model and the I-I model. The Quick Response Freight Manual (QRFM) was used as the starting point for trip generation for the I-I trips. Truck ADT's were available from traffic counts within the modeling area, and an

estimate of VMT by truck type was extracted from the Ohio Statewide Model. Using the average trip length by facility type from the external surveys, the count data, and the statewide model VMT, the QRFM rates were adjusted to obtain area specific trip generation rates. Trip Distribution employs a simple exponential gravity model formulation for each of the three commercial vehicle types (four-tire, single-unit and multi-unit). The ODOT statewide model is used as the source of flows for the E-E component of the commercial vehicles model.

The External Auto Vehicle model has only a work and a non-work purpose. A synthetic model was developed for trip generation as the external cordon lines differed in the developed model from the 1995 surveys. A direct demand model formulation, which is equivalent to a singly-constrained gravity model formulation, was used for the external distribution model. External stations were aggregated into districts, with one to five stations in each district. Internal TAZs were also aggregated into districts. The aggregation was necessary because of the errors in the survey data. The “productions” at each station are based on count data, while the “attractions” are based on the socioeconomic data. As with the CVM, external-external auto trips are expected to be obtained from the statewide model.

Application of the Models

The main model application package is Cube, with TP+ being used for network management, assignment, and other processing. The core tour-based choice models described above are written in JAVA, with direct input/output access to TP+ “skim” and trip table flow matrices. The custom programs are designed to take advantage of the numerous opportunities for parallel processing in the model chain, multi-threading of tasks, and to readily accommodate the addition of computers in distributive processing framework to optimize processing.

The highway network is maintained in database form. ODOT maintains a significant amount of data in its road inventory. An ArcView procedure was written to link ODOT road inventory data to the highway network links. This allows MORPC to routinely update the number of lanes, highway width, and speed limits for use in future networks. Information is maintained for one main highway network database. TP+ procedures were written to create the four period networks from the main database. Differences include the number of available lanes (due to parking restrictions) and the ability to add HOV lanes, HOT lanes, toll facilities, and truck restrictions in different period networks. Skimming procedures are also preformed in TP+.

The transit network is maintained in Viper, with route coding integrated with the highway network layer. Custom programs were written to generate walk and drive connectors to the transit lines. ArcView programs were written to capture the percent short and long walks. Skimming procedures are preformed in TP+.

After the networks are generated and all input files are created for a particular scenario, the custom JAVA programs are executed to implement the tour-based microsimulation

models. A pre-assignment processor step aggregates the microsimulation results, and integrates the commercial and external models to produce four time period sets for transit and highway vehicle demand matrices. After the final trip tables are generated, vehicles are assigned with a multi-class equilibrium assignment utilizing 21 Volume Delay Functions (based on the BPR function) by facility and area type, for four tables – SOV, HOV, Medium and Heavy Truck. Transit assignments are also performed in TP+, with standard reports generated to support analysis and evaluation of the alternatives tested.

Gambling on Microsimulation in Las Vegas: Comparing a Microsimulation Approach with Traditional Aggregate Transportation Models

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Abstract. Disaggregate modeling techniques (logit and nested logit) have been used in Transportation Demand Models since the 70's. Today, almost all urban travel demand models use the logit model to predict mode shares. More recently, many agencies are switching from the gravity model for trip distribution to its disaggregate counterpart, the destination choice model. However, with few exceptions, most urban areas are still applying these models at an aggregate level. That is, while the models have been estimated based on individual level data, the predictions are obtained by applying the models on population averages at the zonal level. However, with advances in computational power (speed and memory) and microsimulation techniques, this is beginning to change. Rather than using zones as the unit of analysis, the microsimulation approach uses a synthetically generated population and applies the models at the level of the individual (or household).

This talk will present the findings from two different implementations of travel demand models for Las Vegas: (1) a disaggregate, microsimulation implementation and (2) a more traditional aggregate implementation. The two implementations are based on similar underlying disaggregate models, and provide a unique opportunity for comparison. The talk is aimed at agencies that currently implement a more traditional, aggregate 4-step modeling approach. The objective is to provide practical guidance on what to expect when switching from a zone approach to a microsimulation application, covering such issues as computation time, implementation issues, and differences in forecasts and analysis capabilities.

Integrating Travel Demand and Traffic Microsimulation Models in San Francisco

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Abstract. Traffic microsimulation model software has advanced significantly in recent years, providing these tools with greater analytic capabilities, facilitating easier development models inputs, and endowing these tools with more robust visualization capabilities. However, when used to support long-range transportation planning analyses, these models are still dependent on external forecasts of travel demand.

Similarly, travel demand forecasting model techniques have also advanced, providing ever more detailed behavioral and geographic detail. However, these models also have their limitations. Traditional network assignment algorithms constrain the ability of these models to support facility-specific transportation planning analyses due to their non-operational nature.

This paper describes a process to leverage the capabilities of both types of models. It presents the methodology used to integrate the San Francisco Model, a state-of-the-art disaggregate activity-based behavioral travel demand forecasting model, with the Doyle Drive Microsimulation Model, an area-wide traffic microsimulation model.

The paper illustrates the capabilities of the activity-based SF Model and describes the significant behavioral, spatial and temporal detail embedded within. It then presents the Doyle Drive Microsimulation Model, which encompasses a large sub-area of San Francisco that includes the Golden Gate Bridge, the Presidio and an extensive local street grid. In addition to the geographic extent and detail, the Doyle Drive Model also includes detailed representations of traveler market segmentation and toll plaza operations.

The primary focus of the paper is a description of the integration techniques used to unite these two models. It discusses the relationship between travel demand model and microsimulation model zones and networks, methods of extracting travel demand data, demand adjustment strategies, and demand loading profiles and peak spreading.

A secondary focus of the paper is a discussion of microsimulation validation and calibration techniques and targets. While extensive literature exists concerning travel model validation standards, there is no current source of information describing generally accepted traffic microsimulation validation standards. The paper presents the adopted targets and associated drawbacks, and addresses the issue of quantitative vs. qualitative assessments of model performance. The paper also discusses the techniques used to calibrate the Doyle Drive microsimulation model.

Microsimulation is an analytic tool or method. The prefix “micro” refers to the fact that the method is characterized by the use of disaggregate units of analysis. These disaggregate units may be individuals, households, vehicles or other units. This paper

describes two very different types of microsimulation models that were used on a single project in San Francisco. These two models each address different aspects of the project analysis requirements. The first microsimulation model is an econometric, utility-based behavioral model which provides detailed information about travelers making discrete choices of travel, including vehicle availability, tour generation (rather than trip generation), time of day, destination, and mode. The outputs from this first microsimulation model then serve as the inputs to a second microsimulation model. This second microsimulation is a detailed area-wide traffic microsimulation model that captures the interactions of individual vehicles on an extended network of local streets and freeway segments around the Golden Gate Bridge. The paper presents the two microsimulation models, and discusses why the choice was made to employ the different microsimulation approaches. It explains how the outputs from the first microsimulation model are integrated into the second microsimulation model. Finally, it addresses calibration issues associated with traffic microsimulation and identifies issues of concern that should be considered when developing or applying microsimulation models.

Advantages of Microsimulation

Microsimulation approaches are used increasingly to support transportation planning functions. The microsimulation framework has always been desirable from theoretical perspective, but recent increases in computational power have made microsimulation approaches practical. One of the most essential and compelling features of microsimulation approaches is their disaggregate nature. From a model development or estimation perspective, disaggregate approaches promise a minimization of model bias and a maximization of statistical efficiency¹. From a model application perspective, disaggregate approaches promise improved policy sensitivity because policies are typically oriented towards influencing the choices of individual decision-makers. For similar reasons, microsimulation approaches offer the advantage of being easier to explain to policy-makers because of the direct connection between a given policy and an expected response by individuals. Finally, microsimulation-based approaches provide for the realization of emergent behavior.

The San Francisco Model

The first of the two microsimulation models is the San Francisco travel demand forecast model, henceforth referred to as the “San Francisco Model.” The San Francisco Model is an activity-based microsimulation model, which forecasts daily activity patterns for individual San Francisco residents. The San Francisco Model is in some ways similar to traditional four-step models in that it assumes that travelers make choices based on the perceived utility of these choices. However, the San Francisco Model is one of the first models to employ the daily activity pattern approach first introduced by Bowman and Ben-Akiva². Activity-based approaches to forecasting demand for travel are based upon the notion that the demand for travel is based on the need for people to participate in activities.

Activity-based models are increasingly attractive as alternatives to traditional trip-based travel demand forecasting models due to growing dissatisfaction with the sensitivities and the accuracy of trip-based approaches. New technologies, pricing strategies, and policy analysis requirements demand that forecasting models represent travel choices, and the contexts in which these travel choices are made, with ever increasing geographic, temporal and behavioral detail. Activity-based models represent a significant advancement because they incorporate more behavioral, temporal, and geographic detail. Because transportation system performance is the result of the combined action of many individual decisions, and many policies are oriented at influencing the choices of individual people, it makes sense to use individuals as the decision-makers in a model. Due to their essentially disaggregate nature, microsimulation methods are well suited for implementing activity-based models.

The San Francisco County Transportation Authority chose to develop an activity-based travel demand forecast microsimulation model because it was felt that this approach would best address the complexities of travel in a dense, multi-modal urban environment such as San Francisco. The model was developed by a consultant team led by Cambridge Systematics. The model was specifically developed to satisfy the analysis needs of the Doyle Drive Environmental & Design Study and support the development of a Countywide Transportation Plan. Each component of the model addresses travel choices in San Francisco more comprehensively than would be possible with a trip-based model. For example, the vehicle availability models, which forecast the number of vehicles that a household chooses to maintain, considers the workplace of the primary worker. In a transit-rich employment center such as San Francisco this is an important sensitivity. The day pattern model and time-of-day models, which predict tours, (chains of linked trips that begin and end at the same location) capture the complex tradeoffs between making additional stops on a tour or making additional tours and are sensitive to shifts in travel by time of day. The mode choice models also capture the complex tradeoffs made by San Francisco travelers, including using combinations of modes on a single tour.

The model system predicts the choices for a full, representative sample of residents of San Francisco County, almost 800,000 simulated individual person-days of travel. A brief summary of the primary components of the San Francisco Model is provided. Additional detail on model development and validation can be found in the references cited^{3,4}.

Synthesized Population: Creates a synthesized population of hypothetical San Francisco residents. This synthesized population represents the fundamental disaggregate units upon which the primary model components rely.

Workplace Location: For each worker in the synthetic sample, this model selects a workplace zone from sampled traffic analysis zones (TAZs).

Vehicle Availability: This model estimates whether a household chooses to maintain zero, one, two, or three or more vehicles.

Full-Day Pattern & Time-of-Day: These models predict the purpose, class, and number of tours made by San Francisco residents and predicts the timing of tours and trips.

Tour Primary Destination and Mode Choice: These models predict tour primary destinations and modes by purpose from sampled zones and six general modes.

Intermediate Stop Location: This model predicts intermediate stop zones on the way to and from primary destinations.

Trip Mode Choice: This model predicts trip mode from eleven more disaggregate modes.

Assignment: While the detailed, disaggregate structure of the microsimulation approach to activity-based modeling is intact from vehicle availability through trip mode choice, the assignment of individual trips is not microsimulation-based. Instead, traditional trip tables by mode are collected from the disaggregate trip mode choice outputs and then assigned to roadway and transit networks using TP+, a widely available travel demand forecasting software set. In the San Francisco Model, traffic is assigned to networks using a standard static user equilibrium method. While equilibrium assignment models have proven to be relatively stable and reliable for providing reasonable volumes and speeds for regional planning purposes, it is more difficult to use these equilibrium assignment outputs when analyzing roadway performance at more fine-grained geographic levels. This is due to both the typical level of detail of travel demand model networks, which usually do not include key operational attributes, as well as the nature of the equilibrium assignment. A theoretical drawback of typical equilibrium assignment algorithms is that the goal of the algorithm is systemwide equilibrium, while real world travelers utilize “individual” user perceived equilibrium, which is somewhat different.

The Doyle Drive Model

The Doyle Drive Environmental & Design Study required analyses of roadway performance for an extensive set of intersections and links in an important area of San Francisco. Doyle Drive is sited within the Presidio, which is the only urban park in the National Park System, and is the primary roadway link serving the Golden Gate Bridge. The Doyle Drive Model, a Paramics-based traffic microsimulation model, was developed to provide both a consistent set of analysis inputs and, due to the project’s prominent location, to provide compelling visual illustrations and animations of the expected roadway performance. In a traffic microsimulation, the behavior of individual drivers and vehicles is modeled on a fractional second basis, guided by a set of global, local and individual parameters such as fundamental rules of motion, characteristics of the vehicle, and rules of driver behavior⁵. From the cumulative actions of these vehicles, it is possible to forecast systemwide performance.

Traffic microsimulation models are becoming increasingly attractive tools to support transportation system impacts analysis. The interest in traffic microsimulation is due to significant advancements in the methodological sophistication of these tools, the relative ease of developing and interfacing with these tools, and the compelling visualizations

produced by these tools. Traffic microsimulation models promise many advantages over typical demand-based equilibrium assignment approaches. In general, traffic microsimulations offer a more unified and realistic approach to traffic analysis because they model the components of network flow directly using detailed networks. A major distinguishing feature of the disaggregate traffic microsimulation framework is that it is sensitive to the complex and chaotic nature of traffic. In addition, the disaggregate microsimulation framework also offers greater policy sensitivity and behavioral realism. Traffic microsimulations can be developed for area-wide networks, which can provide a consistent and integrated basis for analysis and a greater sensitivity to interactive effects of roadway design. Over time, microsimulation models have also become easier to develop due to increased software sophistication, which has greatly facilitated their wider adoption. Finally, traffic microsimulations can provide visual illustrations and animations of system performance, which can be invaluable for public outreach. All these advantages made traffic microsimulation an attractive option for the analysis of Doyle Drive project impacts.

The supply side network detail present in traffic microsimulation models far exceeds the level of detail found in most travel demand model networks. There is both a wider variety of network attributes as well as more accurate operational representations of these attributes. In fact, some of the key input attributes associated with most traditional equilibrium assignments, such as per lane capacity, are not traffic microsimulation model inputs but rather are simulation outputs. For the Doyle Drive project, the network detail was essential because the study area includes an extensive network of both freeway and local street segments and a variety of intersection controls. The study area also includes the Golden Gate Bridge Toll Plaza, which has pronounced traffic metering effects. The Doyle Drive model traffic microsimulation model included a very detailed representation of toll plaza operations, including the separation of vehicle flows into “FasTrak” (electronic toll collection) and “non-FasTrak” market segments.

As stated earlier, equilibrium assignment methodologies are relatively stable, but this stability also indicates a drawback of equilibrium assignment models. Traffic is an ordered, yet complex phenomenon. Particularly at high traffic volumes and densities, small disturbances can have systemwide effects. Disaggregate microsimulation-based traffic models are by design more sensitive to capturing these effects than equilibrium assignment methods. In the Doyle Drive project this sensitivity was useful for evaluating the effects of very high volumes and of toll plaza operations on systemwide performance and also for evaluating the effects of incidents. For example, using the Doyle Drive model it was possible to create simulations of incidents that convincingly demonstrated queue buildup and dissipation was much less pronounced in the build alternative than in the no build alternative. However, microsimulation models’ sensitivity to large scale system performance change resulting from small scale events can also be a disadvantage. These models can be extremely sensitive to very small scale localized coding conventions.

Because traffic microsimulations operate at the level of the individual driver, it is possible to incorporate driver characteristics when considering travel routes. This

provides traffic microsimulation models with more policy sensitivity, and the promise of interfacing directly with disaggregate travel demand model outputs, such as those generated by the San Francisco Model. Ultimately, traffic microsimulation models are dependent on external forecasts of travel demand. The Doyle Drive Model relies on forecasts provided by the San Francisco model and the integration process is described in subsequent sections of this paper. Treating travel demand forecasting and route assignment as discrete, however, is arbitrary, and ideally travel demand and microsimulation assignment models will become more unified.

Traffic microsimulations can be developed for wide areas, making it possible to perform an analysis of system-wide interactive effects, instead of looking only at isolated components. The desire to have a consistent area-wide tool to evaluate the impacts of the Doyle Drive reconstruction was one of the key factors supporting the development of an area-wide microsimulation. Microsimulation models are better suited to analyzing complex or unique roadway conditions, or combined systems of different facility types. Along the mainline segments of Doyle Drive there are numerous weaving and merge/diverge locations. In addition, a significant portion of the study area is a residential neighborhood with a grid roadway network. Accurate representation of the transition from the freeway-like mainline to the grid street network was one of the primary goals of model development.

The set up times for creating microsimulation model networks have been reduced dramatically due to the increased sophistication of the interface tools. The ease of development, however, does vary depending on the software package, and there still is a considerable learning curve for most packages. Due to the network detail required by most models, development of even the simplest models can often take a fair amount of effort. Great care must be taken when developing the networks, as even slight errors in or modifications to network coding can affect systemwide performance.

One of the most obvious and compelling features of traffic microsimulation models is their ability to provide visual outputs, particularly animations, which illustrate system performance. It was this capability that was perhaps the most important influence on the decision to develop the Doyle Drive microsimulation model. Due to the project's highly sensitive location in a national park, and its proximity to the Golden Gate Bridge, it was determined that visual illustrations of the project's expected impacts would be invaluable for ensuring public support of the project. Most traffic microsimulation software comes with the ability to generate both 2-D and 3-D visualizations.

Doyle Drive Model Development

One of the consultant's first tasks was to identify the microsimulation software that would be most appropriate given the analysis needs of the Doyle Drive project. This selection was guided by a number of goals. First, it was desired to use a package that would accept demand inputs in the form of a subarea matrix of vehicle flows, and that the software would provide dynamic routing capabilities. In addition, it was desired that the microsimulation software support reasonable representation of both roadway and transit,

as San Francisco is a highly multi-modal city. Two primary software packages were considered, Paramics and VISSIM. Ultimately, Paramics was chosen because it met the required criteria and because Caltrans, one of the primary project oversight agencies, had recently committed to using Paramics.

One of the unique features of the Doyle Drive traffic microsimulation model is that it is area-wide, covering approximately 7% of the City of San Francisco, includes an extensive roadway network of both freeway and local links, and incorporates a detailed representation of the Golden Gate Bridge toll plaza. Developing a traffic microsimulation model requires extensive amounts of data collection. In addition to the detailed data required to build the actual simulation networks, it is necessary to develop detailed travel demand representing vehicle flows to feed into the model and also to collect extensive calibration and validation data to ensure that the model is generating reasonable results prior to any model application.

The Doyle Drive project team determined that it would be necessary to assess the impact of the project on system performance for three different time periods: the weekday AM peak, the weekday PM peak, and the Saturday weekend PM peak. Because the operational characteristics of the roadway network vary by time of day and by day of week, it was necessary to create three different microsimulation model networks. Examples of key link attributes include the number of lanes, lane widths, grade, speed limits, signposting, and curvature. Examples of key intersection attributes include lane and turn restrictions, intersection controls and associated operational details (such as signal timing), visibility factors, and turning radii and curb positions. Examples of key transit attributes include stop locations, routes, boardings and alightings by stop (which are translated into dwell times), bus stop vehicle capacity and physical dimensions, and schedule. For the Doyle Drive Model it was also necessary to include toll plaza attributes such as booths by direction, as well as booth technology, especially electronic toll collection (“FasTrak”).

It was necessary to create travel demand forecasts for each of these time periods and then disaggregate these time periods into fifteen minute slices. Because of the daily activity approach used in the San Francisco Model, it was possible to generate AM and PM peak period forecasts from a single model run of the existing San Francisco Model. However, in order to generate weekend forecasts, it was necessary to develop a simplified weekend version of the San Francisco model structure.

An extensive traffic count data collection was also undertaken, gathering detailed turning movement at almost 50 intersections in the study area and volumes on dozens of links. Floating car runs were also performed for the primary routes in the study area, to and from the Golden Gate Bridge on all major facilities. In addition, videotape and field visits by the model development team gathered data on queue locations, build up and dissipation. Ultimately, however, even this detailed dataset seemed insufficient for model calibration, as discussed in later sections of this paper.

A significant amount of effort was spent developing a detailed representation of the Golden Gate Bridge Toll Plaza operations. This effort was required for two reasons. First, as stated earlier, traffic microsimulation models are extremely sensitive to small scale network coding conventions. This issue was critical around the toll plaza. Second, additional effort was spent on the toll plaza because, during the time of model development, the Golden Gate Bridge District instituted electronic toll collection (ETC) on a limited number of toll booths. As a result of ETC, the queue that had typically built up on the bridge inbound in the AM disappeared, while a new queue formed further downstream at one of the key transition locations from the freeway to the local street system. The consultant team gathered data on the market penetration of ETC for the Golden Gate Bridge and also gathered historical data on market penetration over time of ETC on other facilities in California. With this information on base and expected future year ETC market share, the demand was separated into two market segments. This process is discussed in further detail in the calibration section of this paper.

Model Integration

As stated earlier, the Doyle Drive traffic microsimulation model relies on forecasts of travel demand provided by the San Francisco Model. A set of integration techniques was developed as part of this effort to establish a consistent method for translating travel demand forecast model outputs, in the form of link volumes, into microsimulation model inputs, in the form of a matrix of zone-to-zone flows. The challenge was not the mechanics of this link-flow to matrix translation but rather how to address differences between the level of accuracy provided by the demand microsimulation model and that required by the traffic microsimulation model. This challenge was further complicated by the area-wide nature of the microsimulation model and the detailed nature of the network.

The solution needed to satisfy two primary goals. The first was to preserve the integrity of the travel demand model outputs to the greatest degree possible, and the second was to provide inputs to the microsimulation model that matched existing counts as closely as possible. The first goal is important because the travel demand model is used to forecast changes in travel demand 30 years into the future, and it was critical to be confident that the method used to link the base year demand model outputs to the microsimulation model inputs would not adversely or arbitrarily distort the forecast year demand. The second goal is important because it would be extremely difficult to calibrate a detailed microsimulation model without relatively accurate input counts or volumes.⁶

The consistency between the travel demand model and microsimulation model zones and networks made the integration approach somewhat more straightforward. Every link and zone found in the microsimulation model is also present in the demand model. However, while the major links in the study area were forecast with a relatively high level of accuracy in the demand model, many of the low-volume local street links were not. Because of the microsimulation model's need for high levels of accuracy even at the level of these lowest volume facilities, it is necessary to adjust the demand model outputs to better provide a better match to observed counts.

For each zone (whether an internal zone or a link at the border of the subarea), the travel demand model identifies the total number of vehicle trips entering the system and exiting the system at that zone. In addition, the matrix identifies the distribution of trips to and from each of these zones to and from all other zones. As expected, the validation dataset identified inconsistencies between the forecast trips and the observed volumes for the subset of zones that are links at the borders of the subarea, requiring a means of adjusting the exported subarea demand matrix. Applying a set of factors based on observed data of vehicles entering or exiting the system would also affect the number of trips exiting the system as well as the distributions of these trips, potentially exacerbating any inconsistencies.

The consultants developed a tiered, hybrid entrance- and exit-based demand adjustment strategy. The demand is primarily adjusted at the entrances, with minor adjustments made at exits on major facilities. The first step in the process is to adjust the entrance volumes on the mainline facilities serving the area. As stated earlier, the travel demand model forecasts for these facilities typically differed from observed counts by less than 10%. Next, a series of screenlines were established around the subarea, and adjustments were made on a screenline basis. The screenline-level adjustment factors were established by comparing the total forecast volumes for the screenline against the total observed volumes on these screenlines. These screenline-level entrance volumes were then distributed to individual links based on the distribution present in the observed counts. Mainline facilities that crossed the screenline were excluded from these calculations. Finally, the entrance-based adjustments did cause exits on streets parallel to major facilities to experience volumes thought to be excessive for microsimulation model calibration. In these locations, a factor was applied to reduce these volumes and to shift these volumes back onto the primary facility.

The methodology is applied for each time period uniquely, based on time-period specific observed data. The method largely preserves the entrance or origin based distribution of trips, and its structure dampens excessive changes in the exit or destination based distribution of trips. This allows the method to be applied to future demand, for which there are no observed volumes, with a greater degree of confidence. This relatively complicated scheme developed by the consultants illustrates one of the challenges of integrating travel demand and traffic microsimulation models.

Calibration & Validation

Once the Doyle Drive microsimulation model networks were constructed and refined, and means of integrating travel demand forecasts from the San Francisco Model were implemented, the consultant team began the laborious process of calibrating and validating the model prior to application. It is necessary to establish standards for calibration and validation, as well as to create a comprehensive set of observed data in order to support model development. At the time of the Doyle Drive Model development, there were no established or recommended standards for traffic microsimulation calibration and validation. Ultimately, measures used for the Doyle

Model proved to be inadequate, as the model met the standards but failed to capture the operational characteristics of the area. However, both the FHWA and the California Department of Transportation have been developing proposed guidelines for traffic microsimulation model development and calibration, which should be available in 2003.

The SFCTA and the consultant team established a set of count- and speed-based criteria for evaluating model performance. Many of the validation criteria did not identify specific locations, but rather established global thresholds for the aggregate number of locations that would meet pre-established targets. At the intersection level, targets were established for gross volumes, approach volumes, departure volumes, and turning movements. For each of these levels of increasing geographic specificity, the standards identified a minimum number of locations that would fall within a given relative error. The allowable relative error increased as the level of geographic specificity increased. For example, it was agreed that at 80% of intersections, the gross volumes would fall within 10% of observed, but that only 60% of turning movements should fall within 30% of observed. For the major facilities within the study area, explicit targets were set. Ideally, the calibration/validation dataset and standards would include a much richer set of information on speeds, travel times, delays, queues, densities, capacities, and traffic volumes, and this information would all be collected simultaneously. The Doyle Drive Model calibration/validation dataset omitted critical quantitative information on delays, queues, densities, and expected capacities. It is also invaluable that the analyst thoroughly understand local traffic operation dynamics. Finally, it is useful to identify in advance key locations that may be subject to closer analysis or consideration and potentially identify more rigorous standards for these locations. In development of the Doyle Drive Model, there were two locations, the toll plaza and a key freeway-local transition point, that were ultimately the focus of much of the calibration effort, and yet neither of these locations were identified explicitly when the standards were established.

Two primary goals guided the calibration of the Doyle Drive Model. The first was to match model behavior and outputs to existing conditions, and the second was to preserve the integrity of the model for future extrapolation. The calibration was iterative in nature. The simulation was run with ten different seeds, and a median run was selected. This median run was then compared to observed data, and any inconsistencies were identified. Potential adjustments to model parameters were identified, implemented and tested on the median run. The simulation was then run again, with ten new seeds, a median run selected, and so on, until the system was deemed to be performing reasonably.

It is critical that the simulations are run numerous times, both during the calibration and validation phases as well as during model application, because of their stochastic nature. Some sources have suggested means of estimating the number of runs required in order to achieve a pre-defined confidence level when comparing alternatives, based on mean values and standard deviations. However, no hypothesis testing or calculation of confidence intervals was performed on the Doyle Drive simulations. In theory, if the random seed is not varied, and the random sequence generation and all other model inputs are held constant, each run of the simulation model should be the same. Interestingly, the consultant team working on the Doyle Drive microsimulation model

found that even when the random seed and all other inputs were held constant, the microsimulation would produce different results when run on different machines. This observation is currently being evaluated by the software developers.

There are literally hundreds of potential parameters to adjust, and so it is a challenge to identify and prioritize the most appropriate parameters. However, due to the demonstrated sensitivities of the model networks, it is necessary to start by first exhaustively checking the networks for coding errors and to ensure consistency. Once confidence in the networks is established, it is necessary to address the key issue of how to make adjustments to global and local parameters. Global parameters might include information about car following, gap acceptance or mean headways. Local parameters might include information related to individual links or intersections, such as lane changes or restrictions on visibility. It is generally desirable to make defensible adjustments to global parameters before fine-tuning local parameters.

To illustrate the types of calibration adjustments made in developing the Doyle Drive Model, it is useful to focus on one of the most challenging locations in the simulation network: the Golden Gate Bridge toll plaza. Although there are models devoted to toll plaza simulations such as KLD's WATSim, Paramics tries to incorporate these behaviors into its traffic simulation package. A variety of parameters were adjusted to calibrate the toll plaza behavior against observed speed and delay, queuing data, videotapes, and analyst observations. The toll plaza has seven "cash" lanes and four "ETC-only" lanes. Due to ETC's significant observed effect on system operations, the trip tables were separated into ETC and non-ETC market segments. However, it was observed that vehicles were not sorting themselves into the proper lanes (color coding the vehicles by market segment helped identify this problem), resulting in unreasonable amounts of congestion upstream of the toll plaza. The expansion of the number of lanes at the toll plaza occurs over only a few hundred feet, which means these shorter roadway links provide inadequate length for drivers to perceive the plaza lanes ahead, make a lane changing decision, and execute that decision. In the calibration process sign posts were installed on several upstream links on the Golden Gate Bridge providing drivers with advanced notice of the ETC lanes. Vehicle headways were also adjusted to promote a denser platooning effect as would be expected in the area of a toll plaza, although this had limited effects. Through a trial-and-error process, ETC lane restrictions were implemented further upstream on the Golden Gate Bridge, ultimately covering almost the full length of the Golden Gate Bridge. This adjustment helped eliminate most of the unreasonable congestion approaching the toll plaza. Toll plaza operations were fine-tuned by splitting the 11-lane link immediately upstream of the toll plaza into two parallel links, one with seven lanes (non-ETC), and one with 4 lanes (ETC), and adjusting the toll plaza link end speeds and stop times to match observed performance.

Conclusion

The use of microsimulation methods promises to greatly enhance the capabilities and defensibility of both long-term travel demand forecast models and operational traffic models. The microsimulation framework can provide greater sensitivity to complex

responses to policies, support increased behavioral, spatial and geographic detail, support more robust model estimation, and provide insights into emergent system performance. In addition, traffic microsimulations can provide compelling visualizations. Given the detailed representations present in the microsimulation models, it is not surprising that expectations of the performance of the models are very high. However, despite the significant advances in making microsimulation software more user-friendly and providing much more flexible tools for model development, developing a robust microsimulation model requires great amounts of engineering and technical proficiency, as well as significant input and validation data. When developing a traffic microsimulation model, it is necessary to establish a variety of calibration targets beyond volumes and speeds, and devote adequate resources to gathering input and calibration/validation data. Extreme care must be exercised when developing networks and calibrating the microsimulation models, and both quantitative and visual outputs should be closely observed and evaluated, particularly at critical locations to determine if performance is reasonable.

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Investigation of Highway and Transit Assignment Variability in the San Francisco Tour-Based Micro-Simulation Model

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Abstract. A key difference between stochastic micro-simulation models and more traditional forms of travel demand forecasting models is that micro-simulation-based forecasts change each time the sequence of random numbers used to simulate choices is varied. This difference has significant implications for using these models to analyze policy; for each scenario being tested, the practitioners must either be run several times and calculate an ‘average’ result, or can run the model only once and hope that the single result is reasonably close to a real average. This paper attempts to explore the number of runs required to obtain ‘average’ highway and transit assignment results through a systematic experiment performed using the San Francisco tour-based micro-simulation models. The San Francisco Model contains models of vehicle availability, day pattern choice, tour time of day choice, destination choice and mode choice. Whereas previous analysis of Monte Carlo error has focused explicitly on vehicle availability, tour generation, destination and mode choice, this paper focuses on the variability of highway and transit assignments that result from varying the random number sequences for each model component over a total of 100 full-model runs. This facet of variability is of particular importance to practitioners looking to tour-based micro-simulation models to provide traditional inputs to decision-making, such as traffic volumes and/or transit ridership estimates. One key feature of this model system is its reliance on aggregate trip-based models for external-internal travel; that is, internal-external trip tables are fixed. This feature is expected to dampen variability in assignments due to differences in model outputs resulting from Monte Carlo error. The paper explores assignment results across multiple dimensions at various levels of geography.

Regional travel demand forecasting has, since its inception in the 1950’s, largely focused on providing decision-makers with demand estimates associated with particular infrastructure investments. The ‘four-step’ trip-based process of travel forecasting, which consists of trip generation, trip distribution, mode choice, and network assignment, evolved in response to expectations that models are to provide reliable and reproducible aggregate and route or link specific demand quantities. The reliability of travel demand forecasts has been addressed through the development of model structures that impose ‘average values’ for travel behavior across similar market segments; for example, an average rate of travel is applied across all households of a particular type. Even where probabilistic model formulations are employed (logit mode choice models, for example), the accumulation of fractional probabilities across market segments ensures reproducible results; in fact, the vast majority of trip-based travel demand models developed in the United States will produce identical forecasts across multiple runs, given the same input data.

A key difference between stochastic micro-simulation models and more traditional forms of travel demand forecasting models is that, in micro-simulation models, running the same model system multiple times with identical inputs does not necessarily result in identical forecasts. This is due to the use of Monte Carlo simulation to select discrete choices according to the probabilities of alternatives for each decision-making unit. If the pseudo-random number sequence used to select alternatives varies between model runs, the alternatives selected may vary. This may be a disturbing feature for practitioners who expect to obtain an average outcome by running the models only once for each particular policy scenario. Since the model results may vary between runs, multiple runs must be performed and the results averaged to obtain a reliable expected outcome. The question then becomes: how many times does the model system need to be run in order to be confident that the average results will be stable? This issue is investigated in this paper by means of a systematic experiment using a micro-simulation model system that has been used in actual planning applications over the last two years.

One of the first activity-based micro-simulation models that has been used extensively in planning is the model system created by Cambridge Systematics and Parsons Brinckerhoff for the San Francisco County Transportation Authority, completed in 2000. The model system was designed to use the “full day pattern” activity modeling approach, first introduced by Bowman and Ben-Akiva at MIT (1). The main feature of the “full day pattern” approach is that it simultaneously predicts the main components of all of a person’s travel across the day. A synthesized population of San Francisco residents is input to the component models of vehicle availability, day pattern choice (tour generation), tour time of day choice (2), destination choice and mode choice (3). Destination and mode choice are predicted at both the tour and the trip level. The synthesized tours and trips are aggregated to represent flows between traffic analysis zones before traffic assignment. The model system predicts the choices for a full, representative sample of residents of San Francisco County, almost 800,000 simulated individual person-days of travel.

In the San Francisco Model, a micro-simulation framework is applied to individuals and households making vehicle ownership, trip pattern, and trip destination and mode choices; many of these models are logit formulations. A Monte Carlo method is used select outcomes according to these logit model probabilities based on random number draws. Each time the sequence of random numbers used to simulate choices is varied, the model result, or ‘end state’ of the model may change. Each model component, with the exception of highway and transit assignment, contains a pseudo-random number generator, which uses an externally provided random seed. In this investigation we varied the external seeds explicitly, which then causes a different sequence of random numbers to be generated. The random number seeds were created using the random number generator in Microsoft Excel. All of the model components were run 100 times for the ‘base’ year 2000, previous to the model components described below, with a different random number sequence for each component in each run.

The variability associated with the sequence of models beginning with auto ownership and ending with tour mode choice was explored in a previous paper (4). Briefly, the SF Models accomplish the following tasks:

- A number of vehicles is selected for each household,
- A day-pattern is selected for each member of each household,
- A time period is chosen for every tour,
- A primary destination TAZ is chosen for every tour,
- A tour mode is chosen for every tour
- An intermediate stop location is chosen for each stop between the anchor location (home or work) and the primary destination for every tour, and
- A mode is chosen for every trip segment on every tour.

Highway Assignment

The highway assignment process is implemented in the HWYLOAD module of TP+. Due to the time requirements of running 100 assignments (approximately 3 hours per assignment on a PC equipped with a 1.2 GHz Athlon processor and 2 GB RAM), only the P.M. Peak Period highway trip tables were assigned for this study, up to a maximum of 30 iterations. In this time period, each assignment ran up to the maximum of 30 iterations. A visual inspection of the gap achieved for each assignment indicates that all 100 assignments were sufficiently converged with an achieved GAP below 0.005, the default for TP+ (5).

Although the highway assignment model is not a stochastic model, the trip tables that are assigned in each model run are variable, and therefore the assignment results will vary. The properties of assignment results under congested conditions are well understood; at volume/capacity ratios greater than 1.0, additional traffic has an exponential effect on travel times due to the steepness of the BPR function. This can cause oscillations between iterations for higher volume facilities, and lower volume facilities that provide access to those higher volume facilities. An additional consideration must be noted with respect to the highway assignment results. The SF Models specifically address residents of San Francisco County. They 'nest' within the Metropolitan Transportation Commission (MTC) regional modeling system. The MTC models are trip-based models whose results are not stochastic. Prior to assignment, the MTC trip tables are factored to create non-resident trip tables for each time period and highway mode, added to the SF Model resident trip tables, and assigned together. As the non-resident portion of the highway assignment trip table for each iteration is constant, the variation in assignment results may be somewhat dampened.

Transit Assignment

The TRNBUILD module of TP+ is used to perform transit assignments in the SF Model. As stated above, although the transit assignment process is not stochastic, the transit assignment results will also vary because the transit trip tables vary between model runs. Since transit network capacity is not considered as part of the transit assignment process, it is not necessary to combine the SF Model and MTC model non-resident trip tables prior to assignment; they are assigned separately. Only the P.M. Peak Period SF transit assignment results are presented in this paper.

Results

Trip Mode Choice

Before examining the highway and transit assignments, it is useful to evaluate the stability of the trip mode choice model outputs. The trip mode choice model is the last of the disaggregate micro-simulation components of the San Francisco Model, and hence the final indicator of pure random simulation error in the San Francisco Model. The variation in the results of the highway and transit assignments that is subsequently discussed in this paper is the result of both random simulation error as well as heuristic nature of the highway and transit assignment models.

The San Francisco Model has two distinct mode choice models. The first model, the tour mode choice model, predicts the primary mode for a given tour and includes six general choices. The second model, the trip mode choice model, predicts the mode for each individual trip segment of a tour, and includes eleven more detailed discrete choices, including different levels of shared ride auto occupancy, and transit submodal detail (local bus, light rail, and heavy rail). This paper presents the results of the trip mode choice models only, but compares the results to the earlier tour mode choice model where appropriate to illustrate the persistent stability of the model system. For ease of presentation, the modes have been aggregated into three classes: auto, transit, and non-motorized. Summary statistics for these results are provided in Table 1. This table also includes summary statistics on the transit submodes, to illustrate the direct model outputs without aggregation.

Figures 1 through 3 present the results of origin-based mode choices, meaning that mode for trips originating in the area are illustrated. Figure 1 presents the results of the origin-based mode choice analysis for transit trips. The figures demonstrate that the county- and neighborhood-level results are very stable, never exceeding a one percent difference from the final means, even after the initial, unaveraged random realizations. Greater variation is evident at the TAZ level, which can be attributed to the relatively rarer likelihood of choosing transit at this disaggregate geographic scale. However, within ten runs, the mean is less than one percent different than the final mean.

Figures 2 and 3 present TAZ-level origin-based analyses of mode choice. Figure 2 shows the earlier tour mode choice results while Figure 3 shows the final trip mode choice results. Given that the trip mode choice model is further down the model system and the results are contingent on the tour mode choice and intermediate stop choice models, one might expect higher degrees of variability in trip mode choice outputs than in tour mode choice outputs. An origin-based analysis of a sample TAZ shows that the trip mode choice results may exhibit slightly less overall variation, and converge more quickly to the final mean than the tour mode choice results. This pattern can be observed in all comparisons of tour and trip mode choice outputs. While the overall number of trips is greater than the number of tours and this contributes to overall higher levels of stability and suppresses the apparent influence of random simulation error, the results demonstrate

that the San Francisco tour-based micro-simulation model does not appear to be subject to a compounding effect of random simulation error.

Highway Assignments

The authors have included a diverse set of summary statistics of highway and transit assignment to illustrate variation in assignment results. Some of these statistics are intended to relate to the earlier model results as closely as possible, such as summaries of total roadway volumes by county and neighborhood, while other statistics reflect the network-based nature of the assignment, such as summaries of volumes by facility type.

Figure 4 shows the summary of variation of total volumes by geographic area. Volumes of all links within the county, a sample neighborhood (the same neighborhood used in earlier model component summaries), a sample screenline (near the selected neighborhood), and adjacent to a sample TAZ (again, the same TAZ used in earlier summaries) are shown. The results show the stability of the total volumes at all geographic scales. At the county, neighborhood, and screenline levels, all runs are within one half of one percent of the final mean. The TAZ-level results show greater variation, but it should be noted that these TAZ statistics include only a single roadway link (bi-directional) adjacent to the selected TAZ.

Figure 5 shows a summary of variation of volumes for a set of sample roadway links of different facility types. A single link from each facility type was selected, rather than showing total countywide volumes by facility. Figure 5 shows that volumes on the selected freeways and major arterial links were the most stable, never differing from the final mean by more than 2 percent. The selected minor arterial and collector links showed slightly more variation, differing from the final mean by up to 4 percent. One surprise in the results was the great volatility of the selected freeway ramp volume. In general, higher volumes correspond to greater stability. However, while the volumes for the selected freeway ramp are roughly comparable to the volumes on the selected major arterial (see table 1), the freeway ramp shows significantly more variation. It is not until almost 50 runs of the model that the mean volume is within one percent of the final mean. This volatility is probably a reflection of the oscillating nature of the roadway assignment methodology on super-congested links.

Overall, the highway assignment results do not appear to show greater levels of variation than the trip mode choice outputs. At all aggregate levels, the greatest variation is typically less than one percent different than the final mean, and a clear convergence to the mean is observed within ten to twenty runs. At more disaggregate levels, the variation between mode choice outputs and highway assignment results is also comparable, with the greatest variation typically less than five percent different than the final mean, and relatively quick convergence to the final mean.

Transit Assignments

Transit assignment results are shown for total system-wide boardings by mode (Bus and LRT) and total. Results are also given for three sample bus routes by ridership (low, medium and high) and a sample LRT line, and for total boardings at a sample transit

station. The bus routes were chosen based on their average ridership and their proximity to the Transportation Analysis Zone and Neighborhoods shown elsewhere in this paper and the previous paper.

Figure 6 shows the convergence for total system-wide ridership for Bus, LRT and total. This graphic is comforting in that total boardings systemwide for all levels of analysis converge to a mean very quickly. Figure 7 shows the convergence of mean boardings for the selected transit routes and station. As expected, the lower ridership bus route shows greater variation and requires more iterations before convergence (approximately 10 iterations are required if the desired tolerance is 1% of the global mean), while the medium ridership route requires approximately 6 iterations before converging to within 1% of the global mean and the high ridership bus route and LRT line require only 2 runs to converge to within 1% of the global mean.

Figure 8 shows the convergence of the maximum load points on the selected transit routes for the 100 runs. This graph shows more variation in maximum load point volume between runs. Note that in this analysis, the maximum load point is defined as the segment of the transit route with the most passengers, and the exact point could vary between runs. In this case, the lowest ridership route requires approximately 30 runs to converge to within 1% of the global mean, the medium route requires 10 runs, and the highest ridership bus route and LRT line require only a few runs to converge.

Conclusions

The analysis conducted as part of this paper indicate that overall, variation evidenced by the San Francisco tour-based models can be reduced through averaging the results across multiple runs. The authors specifically avoid stating acceptable levels of convergence for any given model component or outcome to the final mean as this threshold would certainly depend on the policy being tested and the particular measurement of interest. The plots show a consistent trend (entirely consistent with probability theory and the central limit theorem) that the number of iterations required is inversely proportional to the selection probability and the number of agents making a particular selection.

For example, consider a policy in which a major new LRT line is proposed for downtown San Francisco. Assuming fairly high ridership (one run of the models would yield an order-of-magnitude ridership estimate), the number of iterations required for an indication of the global mean ridership for the route may be only 2 or 3, according to the analysis presented here. However, if the analysis entails predicting the number of boardings at some particular stop, or the forecast of total riders at the maximum load point, several more runs may be required to achieve a mean which is within a few percent of the global mean. Similarly, the forecast of traffic volumes on a major highway may require only three runs according to the analysis presented here, but if the analysis were extended to forecasting volumes for ramps feeding that freeway, many more runs would be required. Additionally, the number of runs required may depend on the comfort level of the ultimate decision-makers about the amount of Monte Carlo variation in the

numbers being used for policy, and the level of exposure (financial or political) of the study in question.

The authors also note that the results presented herein are particular to the San Francisco tour-based models; although the general trends and indications presented here are presumably applicable to other tour-based micro-simulation models, specific instances may yield different results. It would be a useful exercise to conduct the types of analysis presented in this paper within other model systems, both to examine the transferability of the conclusions and to provide analysis specific to those models for future reference as they are used in application.

It should also be pointed out that there is some danger in running these models only once and ‘hoping’ that the indications yielded by that run are reasonably close to a global mean or expected value at anything other than an aggregate level. Table 1 shows descriptive statistics for the figures presented in this paper. The table shows that, for the 100 runs that were conducted as part of this analysis, the minimum or maximum value at the TAZ or link level could be as much as 10 to 20% different from the global mean. It is possible that some other random number sequences could yield percentage differences that are even greater than the analysis presented here.

One major consideration regarding making recommendations about the number of assignment runs required to support different planning analyses is that the highway assignments take far longer to run than the disaggregate activity-based micro-simulation core of the San Francisco Model. Ten to twenty runs of the core behavioral models could be accomplished in 1-2 days, while a similar number of roadway assignments could take 1-2 weeks. This would clearly compromise the usability of the model. One potential means of resolving this issue is rely on the fact that the forecast travel demand is collected to a series of zone-to-zone matrices by mode. The core model system could be run a desired number of times, and the output matrices collected and averaged. This final average set of matrices by mode would then be assigned to the networks. This is a topic for future research.

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FIGURE 1 - Transit Trips (All Levels) - % Difference from Final Mean.

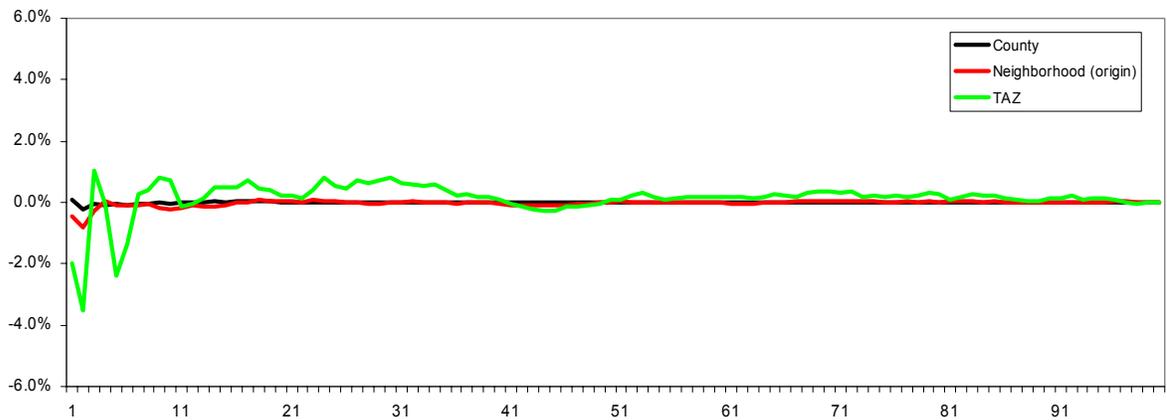


FIGURE 2 - Tours by Mode (TAZ=Origin) - % Difference from Final Mean.

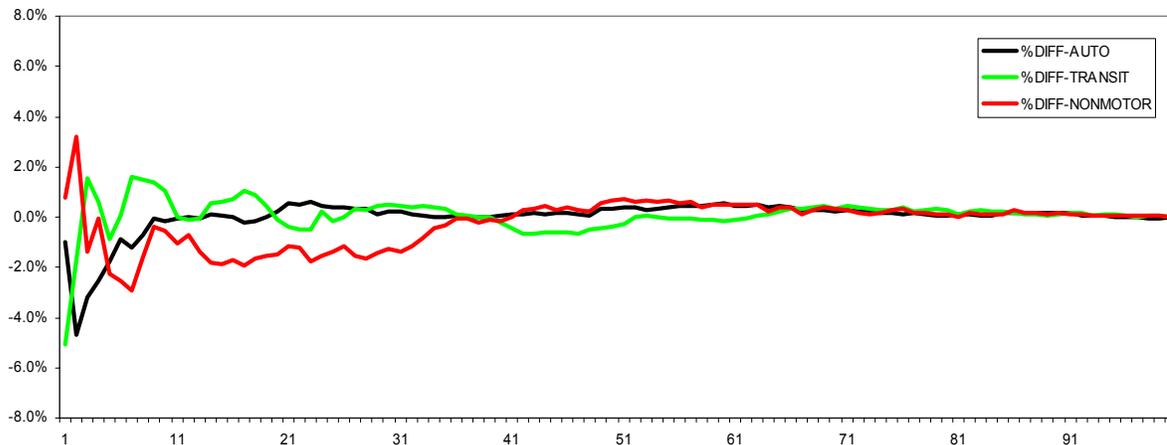


FIGURE 3 - Trips by Mode (TAZ=Origin) - % Difference from Final Mean.

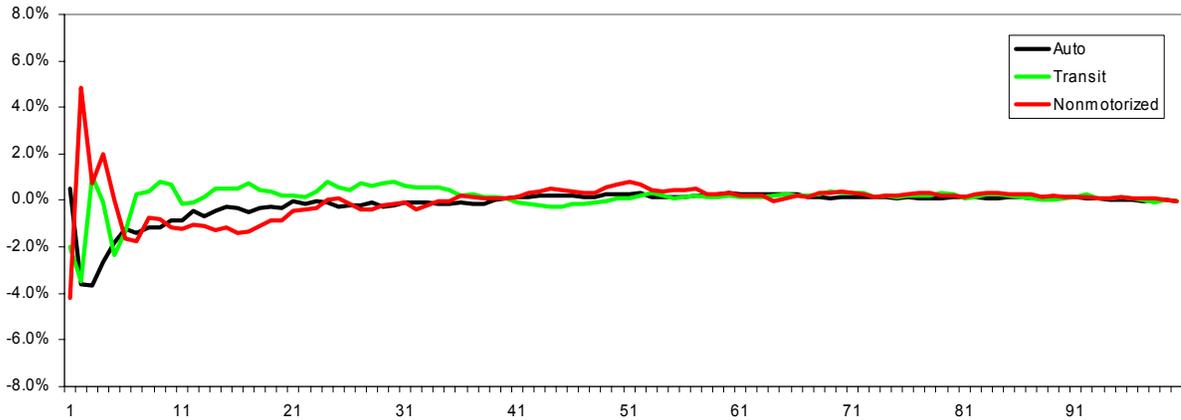


FIGURE 4 - P.M. Peak Period Roadway Volumes by Geography - % Difference from Final Mean.

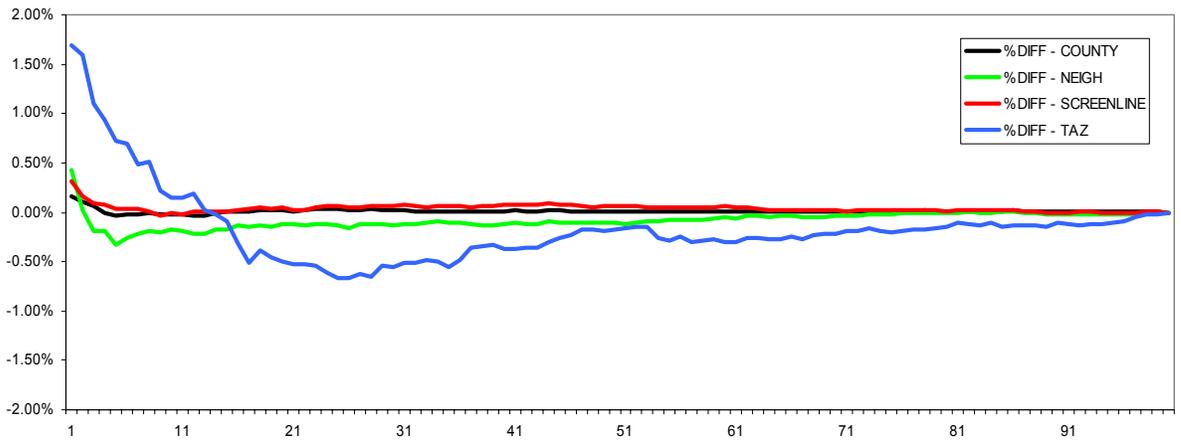


FIGURE 5 - P.M. Peak Period Roadway Volumes by Link (Facility Type) - % Difference from Final Mean.

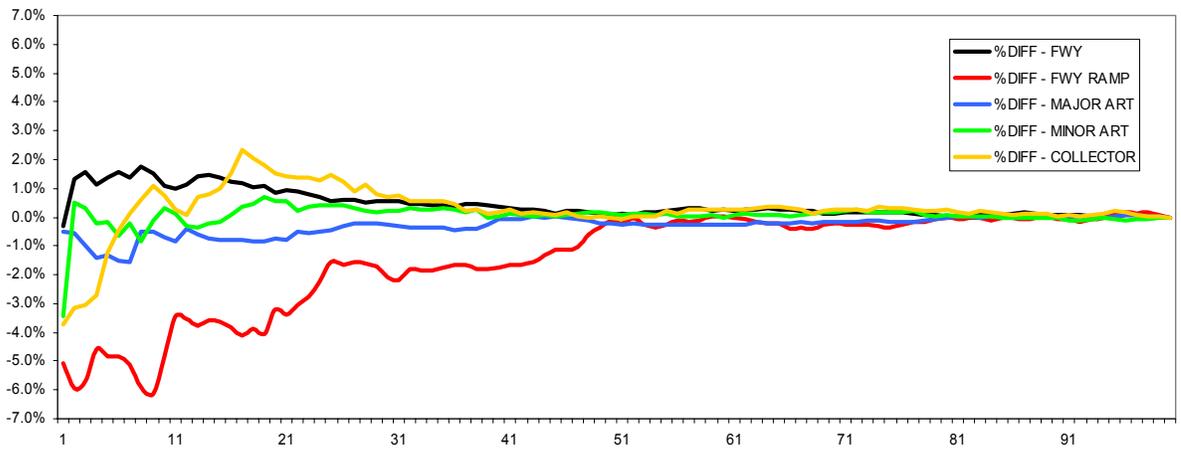


FIGURE 6 - P.M. Peak Period Boardings by Mode- % Difference from Final Mean.

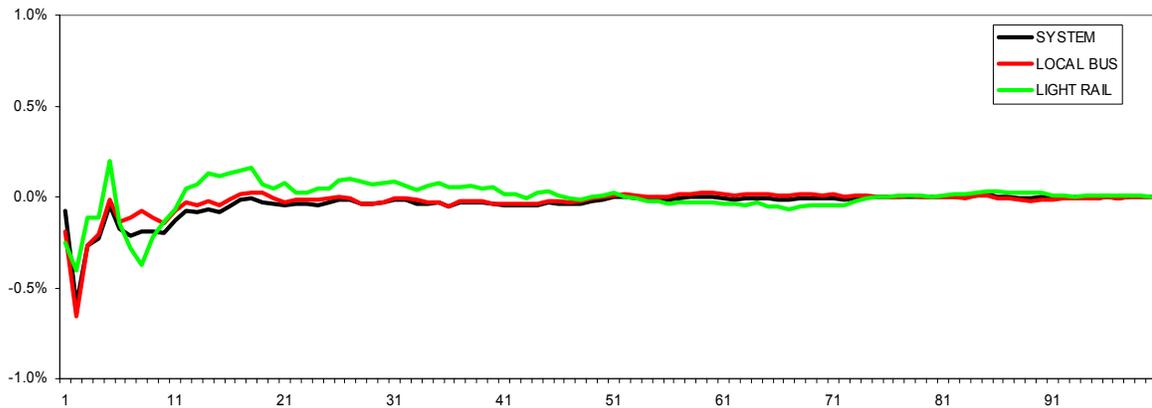


FIGURE 7 - P.M. Peak Period Boardings for Sample Transit Routes - % Difference from Final Mean.

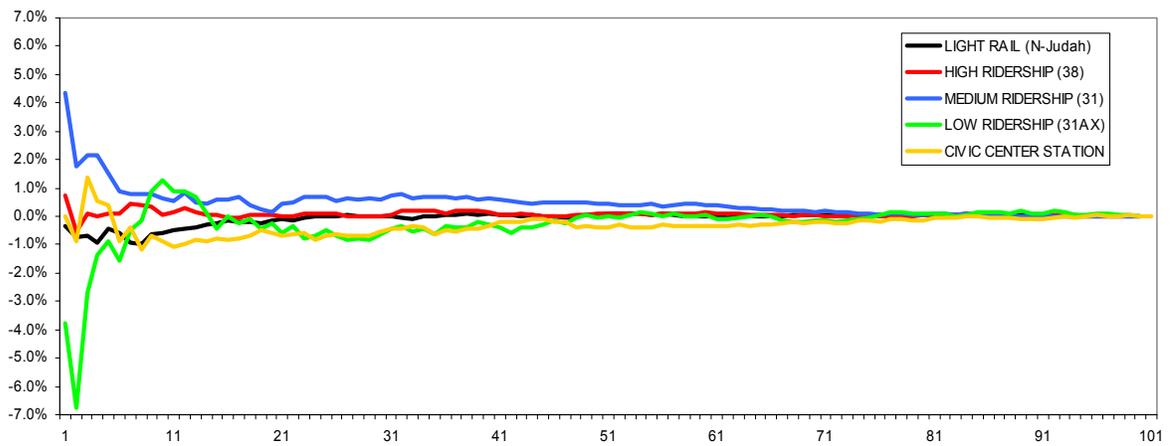


FIGURE 8 - P.M. Peak Period Maximum Load Point Number of Riders for Sample Transit Routes - % Difference from Final Mean.

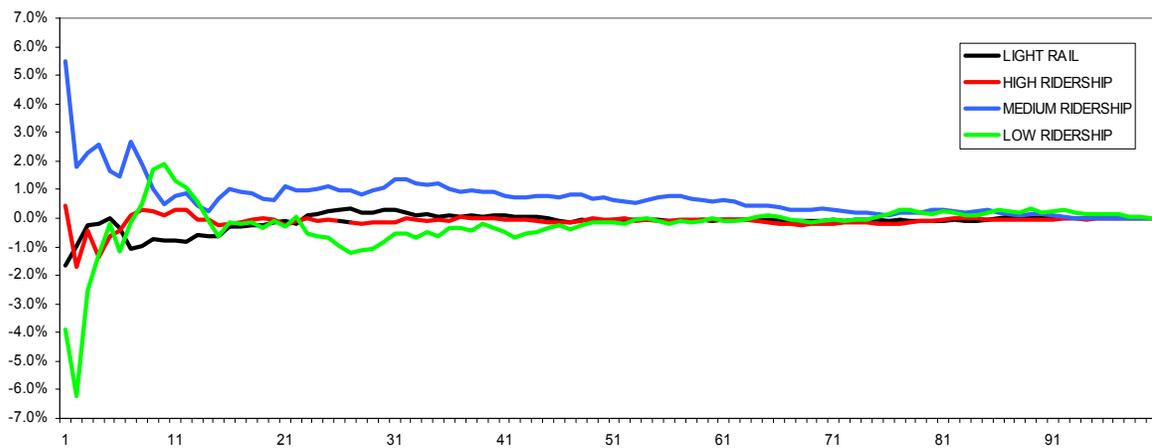


Table 1 - Descriptive Statistics for Figures

FIGURE	LEVEL OF ANALYSIS	MEAN	MIN	% Diff MEAN	MAX	% DIFF MEAN	STDEV
FIGURE 1 Transit Trips (by origin)	County	413,233	410,872	-0.57%	415,474	0.54%	923
	Neighborhood (6)	14,579	14,329	-1.71%	14,930	2.41%	129
	TAZ (246)	363	313	-13.83%	406	11.77%	19
FIGURE 2 Tours by Mode (by origin=TAZ 246)	Auto	1,071	981	-8.37%	1,211	13.11%	33
	Transit	312	276	-11.48%	362	16.10%	17.32
	Nonmotorized	308	253	-17.76%	358	16.37%	20.36
FIGURE 3 Trips by Mode (by origin=TAZ 246)	Auto	1,652	1,503	-9.03%	1,773	7.32%	46
	Transit	363	313	-13.83%	406	11.77%	19.15
	Nonmotorized	527	453	-14.05%	600	13.85%	28.77
FIGURE 4 Roadway Volumes by Geography	County	20,464,973	20,383,839	-0.40%	20,565,471	0.49%	34,932
	Neighborhood (6)	595,750	590,302	-0.91%	603,099	1.23%	2,676
	Screenline (10)	81,538	80,971	-0.70%	82,066	0.65%	279
	TAZ (246)	3,198	3,012	-5.83%	3,342	4.51%	56
FIGURE 5 Roadway Volumes by Facility Type	Freeway	22,155	21,348	-3.64%	23,185	4.65%	465
	Freeway Ramp	5,634	4,908	-12.88%	6,736	19.56%	372
	Major Arterial	7,522	7,197	-4.32%	8,100	7.68%	180
	Minor Arterial	2,714	2,435	-10.31%	2,858	5.31%	86
	Collector	1,344	1,222	-9.07%	1,553	15.60%	61
FIGURE 6 P.M. Peak Boardings	SystemWide	150313	148640	-1.11%	151579	0.84%	577
	Bus	104403	103233	-1.12%	105511	1.06%	445
	Light-Rail	28796	28252	-1.89%	29233	1.52%	205
FIGURE 7 P.M. Peak Boardings	Low Ridership Bus	368	328	-10.83%	404	9.83%	19
	Medium Ridership Bus	1892	1815	-4.09%	2023	6.90%	41
	High Ridership Bus	5397	5253	-2.66%	5607	3.90%	71
	Medium Ridership LRT	6192	6004	-3.04%	6375	2.95%	73
	Station Boardings	1443	1323	-8.34%	1522	5.45%	43
FIGURE 8 P.M. Peak Maximum Load	Low Ridership	295	256	-13.35%	332	12.37%	17
	Medium Ridership	687	630	-8.32%	757	10.16%	27
	High Ridership	1868	1790	-4.18%	1946	4.17%	37
	Medium Ridership LRT	2537	2398	-5.49%	2682	5.70%	47

Development of the Florida Activity Mobility Simulator (FAMOS)

Ram Pendyala, *University of South Florida*; Toshiyuki Yamamoto, *Nagoya University*; Satoshi Fujii, *Tokyo Institute of Technology*; Ryuichi Kitamura and Akira Kikuchi, *Kyoto University*; and Ike Ubaka, *Florida Department of Transportation*

Abstract. Activity-based approaches to travel demand forecasting have seen rapid development in the recent past. Over the past few years, the authors have been working on a major effort to develop a multimodal comprehensive activity-based travel demand forecasting system for the State of Florida. The effort has resulted in the development of FAMOS, the Florida Activity Mobility Simulator.

FAMOS consists of four main modules that together comprise a microsimulation model system for modeling activity-travel patterns of individuals. The four modules are:

- Household Attributes Generation System (HAGS): This module generates a synthetic population of a region together with location and household/person attribute information.
- Prism-Constrained Activity Travel Simulator (PCATS): This module consists of a series of models that simulate the activities and trips undertaken by an individual together with their respective attributes such as locations (destinations), modes, times, durations, and sequence. The key feature of this module is that activity-travel patterns are simulated while recognizing the presence of time-space prism constraints.
- Dynamic Event-Based Network Simulator (DEBNetS): The dynamic network simulator loads trips onto integrated multimodal GIS-based networks along a continuous time-axis.
- Policy Response Option Generator (PROG): One of the major advantages of the activity-based approach is that it offers a powerful framework for analyzing behavioral response to travel demand management policies and transportation control measures. PROG is a tool that models the behavioral adaptation of an individual in response to alternative transportation policies.

The model system has been developed and estimated using household activity and travel data collected in the Southeast Florida region of Florida in 1999. Results of the model development effort have been very promising and have demonstrated the applicability of activity-based model systems in travel demand forecasting practice.

The presentation will provide an overview of the model system together with a demonstration of its features and capabilities as a comprehensive transportation demand forecasting and policy analysis tool.

Using Intersection-based Delay Algorithms to Determine BRT Operation Effectiveness

Kyle Hauger and Richard Walker, *Portland Metro*

Abstract. Portland Metro's South Corridor Transportation Alternatives study called for an evaluation of several transit investment strategies covering seven miles of two heavily-congested arterials; among them, Bus Rapid Transit (BRT). Specific strategies in the study permit BRT buses to receive a travel time and speed advantage over the auto. These include traffic signal preemption and queue jump lanes. To adequately quantify BRT delay savings resulting from these improvements, new intersection-based volume delay functions were used. These algorithms provided an innovative solution for estimating BRT travel time savings over competing modes in the corridor.

Travel time and speed characteristics were identified to express the mobility goals in the BRT alternative. These measurements are based on estimations from traffic assignment calculations within Metro's travel demand forecasting model. A key strategy in the BRT alternative is to separate buses from mixed traffic through intersection-related improvements. Current link-based delay functions, however, do not adequately address the travel time savings of these intersection improvements. In response, more progressive volume delay algorithms were developed to explicitly simulate link traversal time and intersection delay independently.

This paper describes the key equations used along BRT queue bypass and signal preemption intersections in calculating transit travel time savings over the auto mode. It reviews the methodology for collecting and displaying travel time data for the purposes of volume-delay function development. The paper also describes how the new intersection-based delay functions are specified in Metro's traffic assignment model.

While transportation system management (TSM) strategies of queue jump lanes and signal priority systems for public transport have been in existence for some time, the mathematical analysis techniques necessary for quantifying their effects have lagged far behind. This paper addresses the important and timely problems of how to quantify intersection improvements made in transit operations by making use of innovative delay functions in the traffic modeling assignment routine. This paper describes the key equations used in assessing bus rapid transit (BRT) travel-time savings over the auto in designated corridors in Portland, Oregon. This paper also reviews the methodology for collecting and displaying travel time data for the purposes of volume-delay function development.

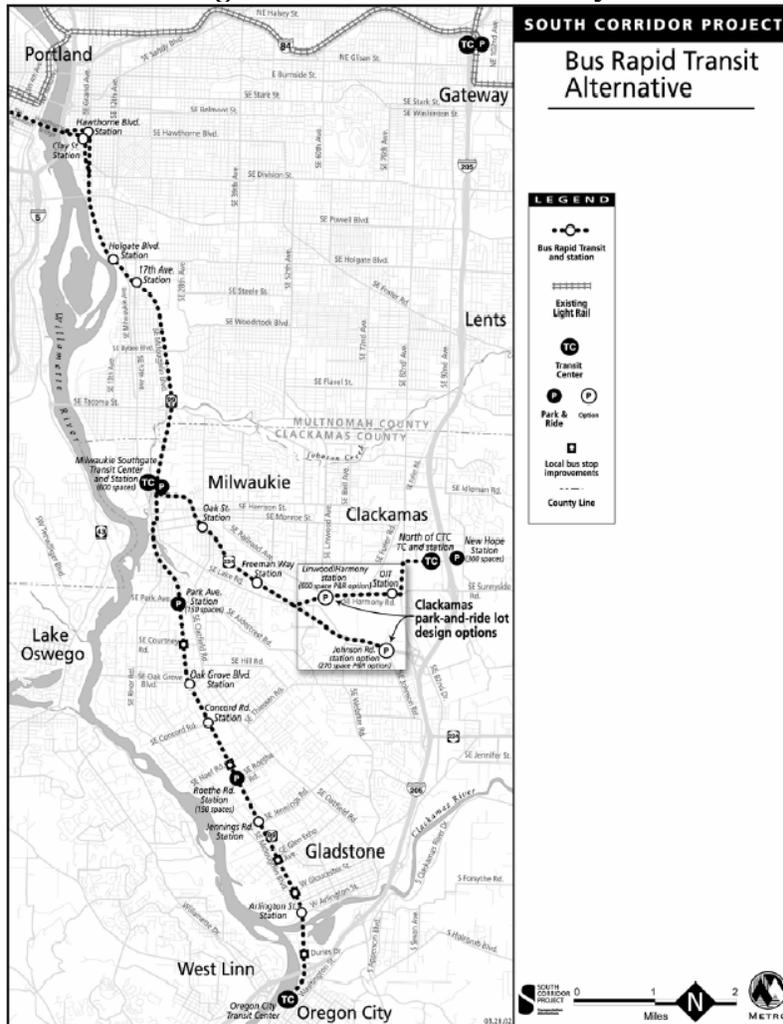
Study Purpose:

Portland Metro's South Corridor Transportation Alternatives study called for an evaluation of several transit investment strategies covering seven miles of two heavily-

congested arterials; among them Bus Rapid Transit (BRT) (See Figure 1). Specific strategies in the study permit BRT buses to receive a travel time and speed advantage over the auto. These include traffic signal preemption and queue jump lanes at the approach intersection. To adequately quantify BRT delay savings, new intersection-based volume delay functions were employed. These algorithms provide an innovative solution for estimating BRT travel time savings over competing modes in the corridor.

Travel time and speed characteristics were identified to express the mobility goals in the BRT alternative. These measurements are based on estimations from traffic assignment calculations within Metro’s travel demand model. A key strategy in the BRT alternative is to separate buses from mixed traffic through intersection related improvements. In response, more progressive volume delay algorithms were developed to explicitly simulate link traversal time and intersection delay separately.

Figure 1 - South Corridor Study



Background

The study of speed-flow relationships is important for several reasons. It is this relationship that forms the basis for many traffic assignment path-building algorithms. These computations influence the evaluation of transportation alternatives, the development of transportation plans, and the determination of conformity with federal air quality standards.

Unfortunately little local data exists to determine the capability of existing functions to address questions as:

- Do current volume delay algorithms reflect observed speed degradation characteristics that are specific to a facility for different volume ranges?
- Are free flow speeds properly specified in current delay algorithms?
- Do existing delay algorithms produce link travel times reflective of both mid-block and intersection delay?

In response, data have been assembled and summarized to advance these relationships at the local level. As a result, intersection delay algorithms have been developed that quantify delay associated with the physical characteristics of the facility and intersection control. In addition, sensitivity to the effects of coordinated signal systems on link travel times has also been included.

The Bureau of Public Roads (BPR) and conical delay functions are two examples of mathematical algorithms defined in estimating the relationship between speed and traffic flow. In most of their applications however, delay is considered only at a link level.

In areas where intersections can cause significant delays, their impacts are high on total link travel time. In some cases, improving signal timing plans at downstream intersections can prove more cost advantageous than widening existing facilities. In others, incorporating a system of coordinated signals is effective at reducing corridor travel times. As a result, current traffic assignment models should be sensitive to incorporate these and other transportation system management strategies into traffic assignment simulations.

Data Analysis

Factors known to affect link travel times include the link length, free-flow speed and the volume-to-capacity ratio. The first element of any link travel time function is the journey time needed to traverse the facility under non-congested (i.e. free-flow) conditions. This term is independent of flow on the link and is treated as a constant in the travel time function. The uncongested journey time is dependent upon two variables: link length and free-flow speed. For the purposes of this study, link distance is fixed and was unchanged. Free-flow speeds were specified using GPS travel-time collected data at low volumes.

The second element of link travel time functions is the volume-delay term. Quantifying this term as it relates to the congestion at the downstream intersection requires volume-

to-capacity analysis of the link. The result is a multiplier term that exhibits speed degradation characteristics at increasing volume levels.

Volume-Delay Specification

Intersection Approach Delay

The specification of intersection delay functions are based upon approach attributes relating to the difference in functional classification of intersecting links and the approach type of arriving vehicles. Functional classifications are based upon the FHWA highway functional classification guidelines. Through field data we observed that signal cycle lengths had a strong influence on intersection stopped delay. We related the variation in cycle lengths to the functional classification differences at intersecting links.

A difference of 1 or less in functional classification at the intersection on average exhibited higher average cycle lengths and a higher delay value. This was common at intersections where more sophisticated signal phasing conditions existed and conflict and competition for green time was maximized. Where 2 or more difference in functional classification at the intersection was noted, signal cycle lengths were observed to be lower in value. High turnover in cycle phases gave these conditions a lower delay value.

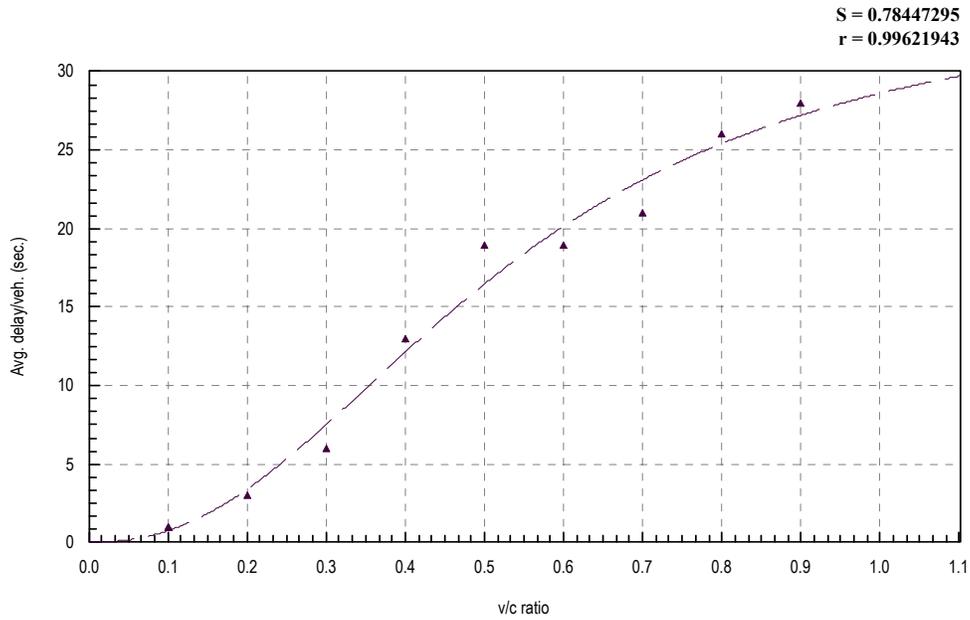
Intersection arrival type is categorized by uniform or random, relating to the measure of vehicle progression at the intersection approach. From field data it was observed that signal density has a strong influence on arrival patterns. Two possible distributions of the time between the arrival of successive vehicles were assumed in this study. First, equal time intervals (derived from the assumption of uniform, deterministic arrivals) and second, probabilistic distributed time intervals that account for the randomness of vehicle arrivals at signalized intersections.

In total, three variations of intersection delay are specified. Segmenting intersection stopped delay profiles into three distinct functions considered both the geometry of the intersection and the distribution of traffic movements. In general, the quality of flow (measured in terms of delay) along a street is a function of the functional classification of intersecting streets, signal spacing, and the traffic signal cycle length.

The highest delay is incurred from random arrival patterns with 1 or no functional classification difference. Figure 2 shows the specification of random arrivals with 1 or no difference in functional classification at the intersection. As can be seen from the scatter plot, as vehicles begin to arrive at the intersection, delay accrues at an increasing rate.

Delay begins to increase rapidly beyond v/c ratios of 0.2. As through field data, these characteristics are typical of intersections exhibiting random arrival patterns where g/C times are proportional amongst all approaches to the intersection, and cycle lengths trend high resulting in longer queues at high volume levels. Average vehicle stopped delay is significant at these approach types, although at very low demand/capacity levels vehicles may randomly pass through the intersection without stopping.

Figure 2 - Random Arrivals, 1 or no Functional Classification Difference



$$fd = (a*b+c*x^d) / (b+x^d)$$

where:

$$a=0.034807783 \quad b=0.22996809$$

$$c=35.210296 \quad d=2.3015579$$

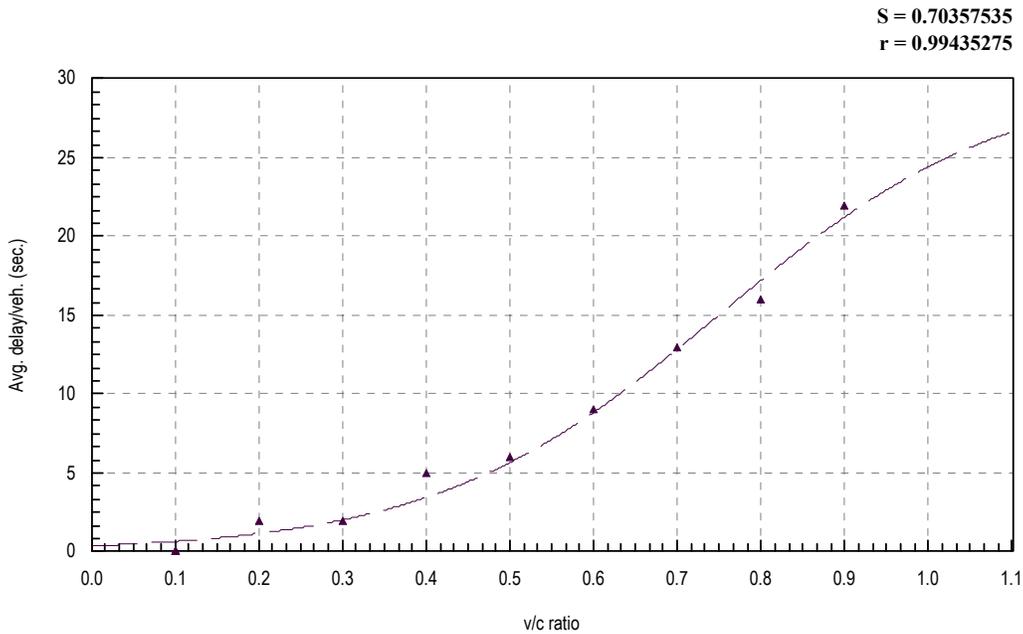
$x = \text{volume/capacity}$

$$S = 0.76447295$$

$$R^2 = 0.98$$

The second highest intersection delay value combines random arrivals with 2 or more difference in functional classification with uniform arrivals, 1 or no functional classification difference at the intersection. Figure 3 illustrates the specification representing these conditions. The regression line shows that at low v/c values (below v/c ratio's of 0.4), delay increases at a moderate rate, with a soft upward slope (beyond v/c values of 0.5).

**Figure 3 - Random Arrivals, 2 or more Classification Difference;
Uniform Arrivals, 1 or no Classification Difference**



$$fd = a / (1+b*exp(-cx))$$

where:

$$a=30.120694 \quad b=79.33512$$

$$c=5.8360481$$

$x = \text{volume/capacity}$

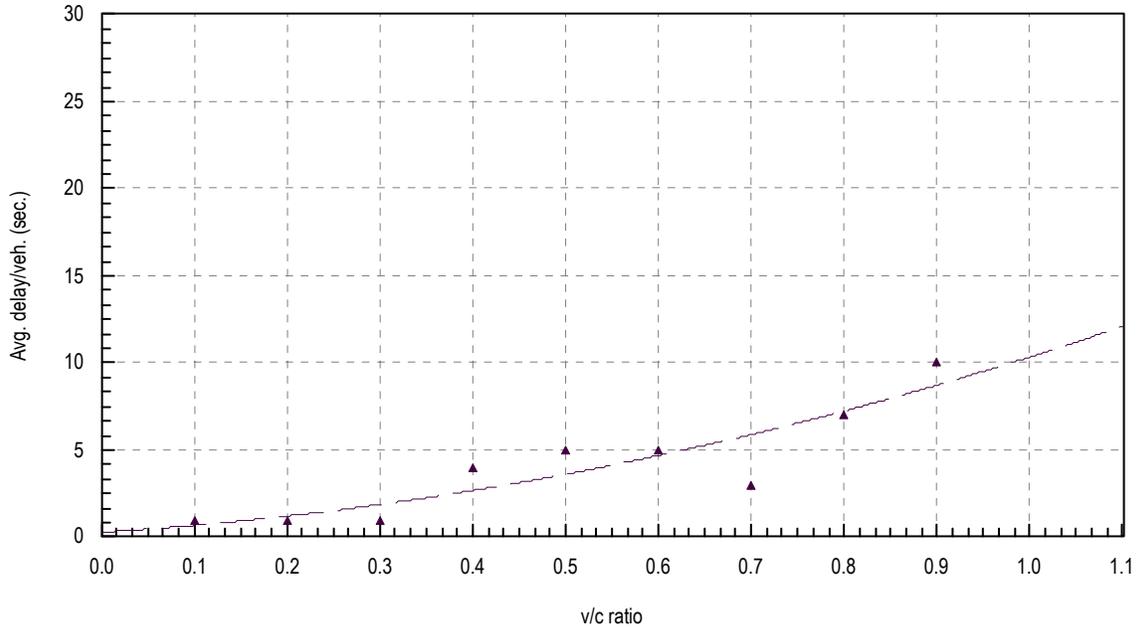
$$S = 0.70357535$$

$$R^2 = 0.98$$

The lowest average delay occurred at intersections demonstrating uniform arrival patterns with 2 or more classification difference at the intersection. Figure 4 shows the relationship between observed average delays of uniform arrival patterns with 2 or more classification difference at the intersection and varying v/c levels. Along all flow rates, moderate delays in the functional relationship are illustrative of the vehicle ‘bunching’ phenomenon observed in field data. Flows observed at these intersections take advantage of optimized signal timing and sufficient green times to minimize average delay. The graph shows a soft upward sloping curve representing low delay values at the intersection approach.

Figure 4 - Uniform Arrivals, 2 or more Classification Difference

S = 1.45614090
r = 0.91392954



$$fd = a+bx+cx^2$$

where:

$$a=0.290909 \quad b=3.2575758$$

$$c=6.8181818$$

$x = \text{volume/capacity}$

$$S = 1.45614090$$

$$R^2 = 0.82$$

Worth mentioning from the above intersection delay specifications are the regression shapes in Figure 3 and 4. As volumes approach capacity an inflection point is present where the functions take an ‘S’ dimension. Delay values beyond capacity bend toward a moderating rate of increasing delay so as to limit the exaggerated delay that occurs when volumes go beyond capacity. Maintaining this property allowed for more realistic estimated travel times that validated against field observations.

Mid-Block Delay

Two principal components make up the total time that a vehicle spends on an arterial: the mid-block running speed upstream from an intersection and the impedance at the intersection approach. This section will discuss in detail the specification for functions relating to mid-block speeds (or its inverse travel time) upstream from an intersection.

GPS running speed measurements taken prior to the intersection approach were used to specify mid-block speed conditions. Results from field observations indicate that volumes had virtually no effect on mid-block speed degradation. The drawback of using these data to develop mid-block travel time functions is its inability to predict speeds as a decreasing function of volume. This condition is a long-standing requirement for satisfying the Frank-Wolf algorithm for calculating equilibrium traffic flows. Without this requirement, assignment results would have multiple solutions per OD pair.

The mid-block delay function (Figure 5) takes a traversal time form with an added delay term. This added term in the final equation adds an additional slight delay as congestion rises. The added increase in travel time helps to impede the assignment of additional traffic on an upstream link from the signal as volumes approach capacity.

Figure 5 - Mid-Block Link Delay Estimation

$$Y = ((60 * \text{length}) / \text{speed}) * 1.05$$

Where:

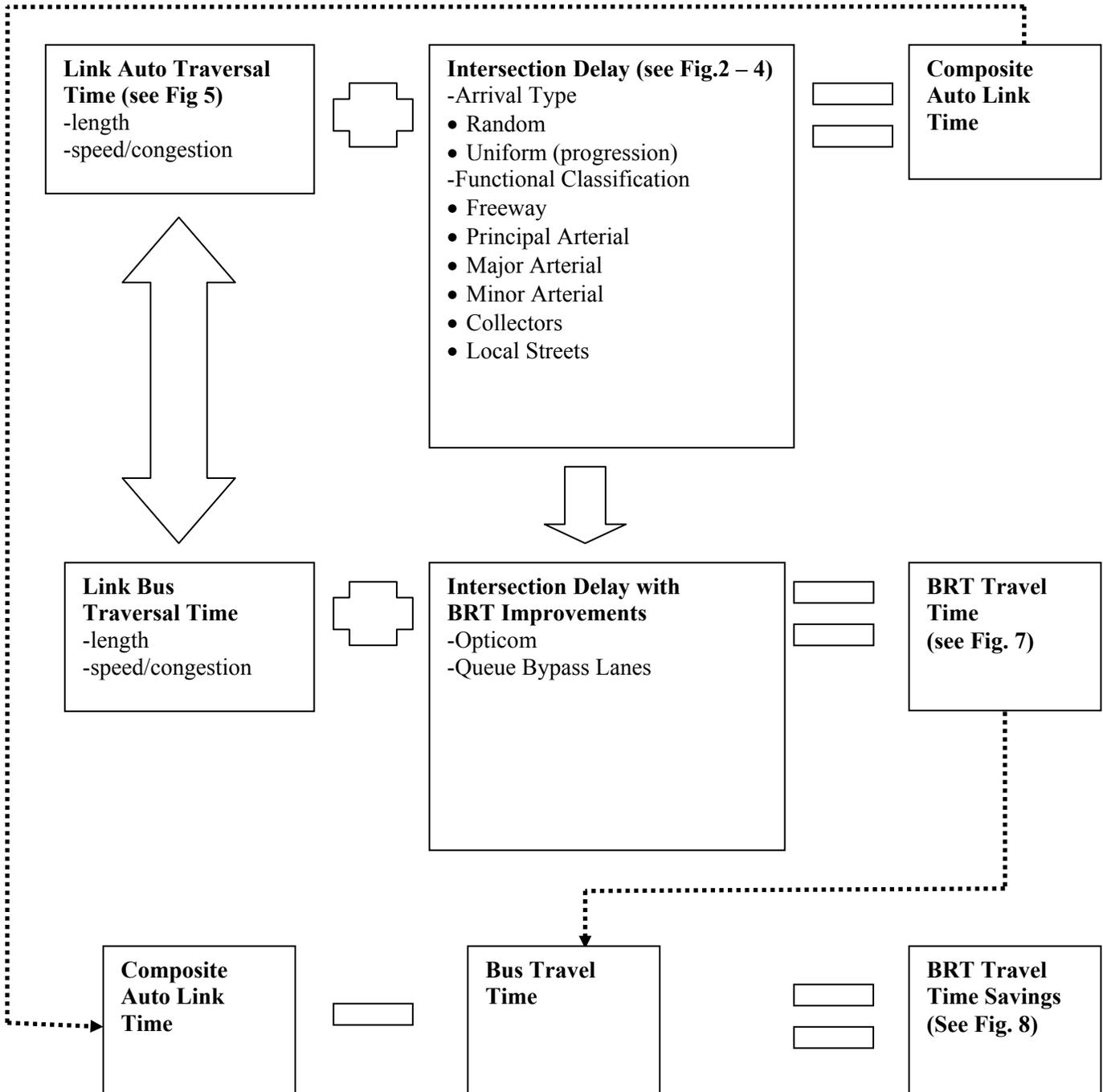
Y = Mid-block link delay

1.05 = added delay term

Study Application

For the purposes of estimating BRT travel time savings, both the mid-block delay and intersection delay functions were first added together to compute a total composite link delay. This term accounts for the two primary components that make up total travel time a vehicle spends on an arterial: mid-block journey speed and intersection delay. Next, the average savings in signal timing delay due to transit signal priority and queue jump lanes is computed using ½ of the computed intersection delay. From a practical perspective, Figure 6 shows the South Corridor study BRT travel time savings estimation methodology.

Figure 6 - South Corridor Link Estimation Methodology



Once calculated, composite auto link travel time (link traversal time and intersection delay) is carried forward to estimate BRT travel times and travel time savings on facilities bypassing the intersection approach queue using the equation in Figure 7.

Figure 7 - BRT Travel Time Estimation

$$Y = ((60 * \text{length}) / \text{speed}) * 1.05 + (0.5 * \text{INT})$$

Where:

Y = BRT travel time (minutes)

INT = subject approach intersection delay

Figure 8 illustrates the final equation used to calculate transit travel time savings.

Figure 8 - BRT Travel Time Savings

$$Y = \text{composite link auto time} - \text{bus travel time}$$

Where:

Y = BRT time savings (sec.)

composite link auto time = link traversal time + intersection delay

Conclusions and Future Research

The Portland Metro South Corridor study requirements have brought forth the need for enhanced corridor travel time estimation. Mid-block delay and intersection delay estimation are a central component of these requirements. Data collected from field studies have provided a basis for identifying the extent, severity and specific locations of congestion problems on a system-wide basis. In addition, these data can be used to track longitudinal changes in congestion and provide further sensitivity to changes in supply/operating characteristics reflective of the street system in traffic assignments.

This paper has presented methods to compute BRT travel time savings as computed in the South Corridor study in Portland, Oregon. By categorizing roads into basic types that are representative and prototypical of others, sample data were quantified to measure congestion at mid-block conditions and at the intersection approach. Derived from GPS travel time runs and stop watch measurements, four distinct volume-delay algorithms have been developed. These algorithms provided an innovative solution for estimating BRT travel time savings over competing modes in the Corridor.

INTDAS: An Integrated National Transit Database Analysis System

Ike Ubaka, AICP, *Florida Department of Transportation* and
Albert Gan, Ph.D., *Florida International University*

Abstract. Agencies rely on various sources of data to help plan, manage, and improve transit facilities and services. Examples of these data include the National Transit Database (NTD) from the Federal Transit Administration (FTA), socioeconomic data from the Census Bureau and planning agencies, transit route data from transit agencies, land use data from county tax appraisal offices, etc. Although such data are generally available for transit planning, they are not easily accessible to transit planners. To remove the data barrier, the Florida Department of Transportation (FDOT) Public Transit Office decided to develop a user-friendly information system called the Florida Transit Information System (FTIS). The system integrates various data sources into a common data depository and provides customized functions for easy data retrieval and analysis. The current system consists of two major components: (1) INTDAS (Integrated National Transit Database Analysis System), and (2) FTGIS (Florida Transit Geographic Information System).

INTDAS is designed to retrieve and analyze the National Transit Database (NTD)—a uniform data set required by the FTA as a prerequisite for the nation's transit systems to receive FTA grant funds. The current INTDAS database combines the 1984-2000 NTD data for all transit systems reported to the NTD program. The system provides customized tools for easy data retrieval, visualization, analysis, and transfer. FTGIS, on the other hand, is a stand-alone GIS system developed using ESRI's MapObjects 2.0 library. The system is customized for easy access to several bundled GIS shape files pertaining to Florida's transit systems. It also includes a comprehensive set of GIS functions ranging from basic zoom-in and zoom-out operations to highly customized buffer zone analysis. This paper will introduce the system architecture, the data integration process, and the various database and GIS functions developed for the system.

INTDAS (Integrated National Transit Database Analysis System) is a major FTIS system component designed to facilitate the retrieval and analysis of multi-year, multi-system data from the National Transit Database (NTD).

What is NTD?

Each year, more than 500 of the nation's transit agencies report data to the FTA for inclusion in the NTD—a uniform data set required by the Urban Mass Transportation (UMT) Act as a prerequisite for the nation's transit systems to receive the FTA grant funds. Known formerly as the Section 15 database, NTD includes data on transit organization characteristics, vehicle fleet size and characteristics, revenues and subsidies, operating and maintenance costs, safety and security, vehicle fleet reliability and inventory, and services consumed and supplied. These data have been used extensively to derive values

for transit performance measures and have become the sole source of standardized and comprehensive data for use by all constituencies of the transit industry.

Why INTDAS?

As a major source of performance data for the transit industry, an important application of NTD has been for use in trend analyses that require multiple years of NTD data. However, accessing multiple years of NTD data is currently a very tedious process. One major reason is because NTD data are collected and distributed annually on separate files. To perform a trend analysis, for example, one must learn about the file structures that may vary from year to year, identify the specific variables of interest from the vast number of potential NTD variables, and then extract the corresponding data values from the specific files for the specific transit systems. For a ten-year trend analysis, for example, this process must be repeated ten times, one for each data year. After the trend values are separately extracted for each of the ten years, they must be entered manually into a spreadsheet or a statistical program for analysis. This process is very cumbersome and is prone to errors. Clearly, a solution to the data accessibility problem is to develop an integrated database system, such as INTDAS, that (1) combines the individual NTD data files from multiple years into a single, standardized database, and (2) provides customized tools for quick and easy data retrieval, visualization, and analysis.

INTDAS is one of the two main components of the Florida Transit Information System (FTIS). The other, is the Florida Transit Geographic Information System (FTGIS), a stand-alone transit GIS.

Trains To Planes: The DFW International Airport Rail Access Planning Study

Greg J. Royster, P.E., *North Central Texas Council of Governments*

Abstract. The term, “seamless transportation” is defined as a direct, efficient, convenient, and reliable system of travel. The challenge for any metropolitan area is to create such a system. The mission of the North Central Texas Council of Governments (NCTCOG), the Dallas/Fort Worth International Airport (DFW), Dallas Area Rapid Transit (DART), and the Fort Worth Transportation Authority (FWTA) has been to identify, develop, and implement the best method for connecting centrally located DFW International Airport to the regional rail system. That system represented in the region’s Metropolitan Transportation Plan includes three elements: 1. Trinity Railway Express (TRE) commuter rail (in operation with over 7,500 riders per day), located south of the airport running between the cities of Fort Worth and Dallas, 2. Light Rail, currently undergoing an EIS as a result of the Northwest Corridor Major Investment Study, located to the east of the airport stretching from downtown Dallas to the eastern most portion of airport property, and 3. Planned commuter rail to the north of the airport from downtown Fort Worth to the northern suburb communities of Dallas. In addition to the Trinity Railway Express, the recommendations of the Northwest Corridor MIS, and regional rail plans, this study included analyses of and recommendations for the appropriate alignment, rail technologies, planning level terminals/stations, operational plans, funding opportunities, and multimodal interface. Other issues considered were existing and proposed bus systems, taxi and shuttle queues, passenger and employee parking facilities, the Airport’s consolidated Rental Car Center (RCC), and Automated People Mover (APM) system, which is under-construction.

The issues for this study were complex, in that 22 alternatives, each with detailed cost and ridership estimates, were identified and analyzed. Using the Regional Travel Demand Model, mode choice output was compared against other U.S. cities for mode shares with airport connections. A technique of determining person trips as a function of passenger enplanements was employed in the travel model, resulting in a viable method for determining daily person trips. In addition, innovation on the public involvement side was achieved by grouping sets of alternatives into four “service families”. This proved to be successful in communicating and soliciting ideas, concerns and comments from citizens and other stakeholders. Consensus on a final recommendation was reached during the April public meetings of this year.

The final recommendation is to bring commuter rail from the northwest without transferring and light rail from the east, both directly to the airport’s future central terminal area. Flexibility for a tunnel option remains along with an option to locate an at-grade alignment through the southern portion of the airport. Existing bus service from the TRE will continue with a preservation of clearance, or “gateway” across S.H. 183, the east-west freeway to the south of airport property. Final engineering and environmental analysis is the next step to ultimately creating more rail options for travel throughout this region. Other high growth regions faced with meeting goals of Air Quality State Implementation Plan commitments to reduce emissions, increasing their ability to complete for world-class events such as the Olympics, and creating a more reliable system of travel can benefit from lessons learned from this study.

Using the Principles and Rigor of NEPA in Long-Range Planning

Craig T. Casper, AICP, *Wilbur Smith Associates*

Abstract. The Bay-Lake Regional Planning Commission's *Northside Traffic Circulation Study* evolved out of a long-standing controversy in Sheboygan, Wisconsin. Wilbur Smith Associates (WSA) was contracted in 1999 to undertake a 12-month study to recommend the most efficient and effective thoroughfare plan for a sub-region of the Metropolitan Planning Area. Almost immediately several basic tenets of the standard traffic planning process were challenged. During the first public meeting numerous citizens criticized the limits of the scope of the project. They rejected the notion that more detailed social, economic, and ecological impacts would be conducted during later phases of project development

The project evolved into a blend of traditional long-range planning and order of magnitude NEPA-type evaluation of social, economic, and ecological impacts. Transportation goals and objectives were developed, along with supporting policies. Additional data gathering, accompanied by an expansion of the study area into one that was more logical and neighborhood inclusive also occurred. Membership of the Steering Committee included the Wisconsin Department of Natural Resources, and several other stakeholder agencies. The representative from WisDNR was able to provide data about wetlands and federal and state Endangered, Threatened, and Species of Concern that are known to occur or have habitat in the project area. Detailed water quality, air quality, and floodplain information was also gathered when readily available from existing sources.

After some basic assumptions about construction parameters were made, we utilized detailed GIS files to locate the potential alignments or expansions of roads, determine a footprint, and quantify potential impacts. The final recommendation likely did not include any options that would not have been included in a standard study, but it likely excluded at least one option. After great initial controversy, this process produced a final recommendation that some disagreed with, but all acknowledged was inclusive and fair. The final project report, complete with purposes and needs for individual options, was submitted in Mid-August 2002.

During conduct of this study, we began to believe that the doing the following could improve the quality of transportation decision-making:

- Include resource agencies and other stakeholders in the long-range planning of transportation infrastructure.
- Approach the goals and objectives of a long-range plan in a manner similar to purposes and needs of a NEPA document. Include and evaluate alternatives to satisfy these goals and objectives.
- Educate the public and decision-makers on the differences and tradeoffs between context, intensity, and longevity of impacts.
- Utilize GIS technologies to get order of magnitude impact evaluations.

We believe that this pre-NEPA investigation and acknowledgement of impacts could speed the environmental process, lead to better project design and impact mitigation, and more cases of windfall benefits/fewer cases of wipeouts, as competing projects or programs are minimized or eliminated.

Link-Based Calculation of Motor Vehicle Air Toxin Emissions using Mobile 6.2

William R. Stein and Dick Walker, *Portland Oregon Metro*

Abstract. EPA's MOBILE 6.2 model allows transportation planners to respond to community concerns by calculating air toxin emissions from motor vehicles. Metro partnered with EPA, ICF Consulting, and the Oregon Department of Environmental Quality in estimating emissions of 27 hazardous air pollutants at the link and zone level. This presentation describes the emission calculation algorithms that Metro developed for use in EMME/2, MOBILE, Stata, and Oracle.

The chosen approach involved splitting daily vehicle volumes into seven periods to represent congestion at different times of the day. Multiclass assignments were conducted in EMME/2 to track vehicle movements by fleet; the fleets accounted for differences in vehicle age profile by county and in inspection/maintenance program by state. Trips and VMT were then allocated from the seven assignment periods to each hour of the day using factors from Metro's household activity survey.

Separate MOBILE runs were conducted for each combination of the five fleets, two seasons, four link types, and (on freeways and arterials) 14 speed bins. Emission rates for five of the pollutants of interest were automatically produced by MOBILE 6.2, while most other toxins required the use of Additional HAPS inputs. For each pollutant whose emissions vary by speed, speed curve equations were generated in Stata to allow the calculation of emissions at any speed.

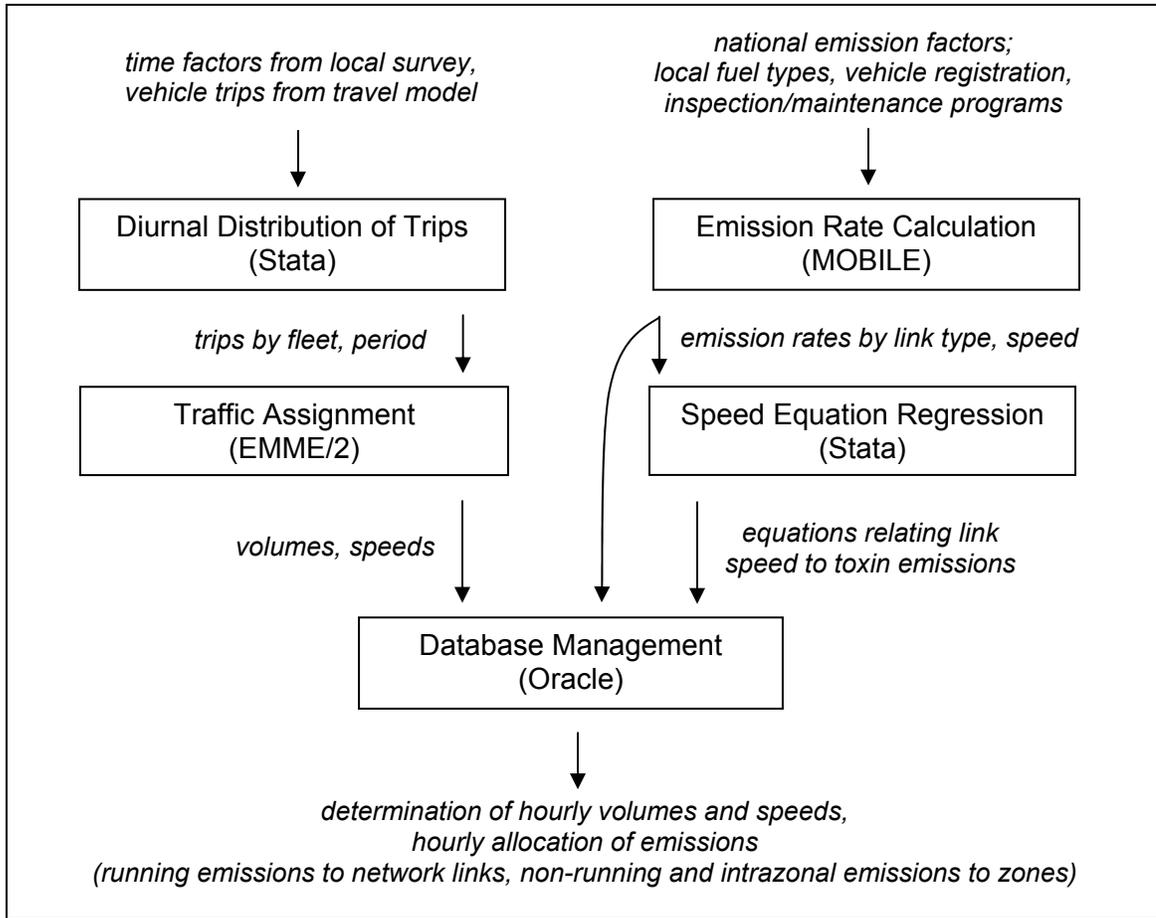
All the data were exported to an Oracle database. MOBILE's emission rate factors were applied to each link to calculate running emissions at every hour of the day. Emissions from intrazonal travel, as well as all non-running emissions, were calculated then allocated to each trip's origin zone.

Metro plans to use this link-based methodology for future air quality conformity work. The queries and programs developed for this study can also be adapted for use by other agencies with a need for geographically detailed analyses of motor vehicle emissions.

This document describes the algorithms Metro developed to calculate hourly air toxin emissions by roadway link and travel analysis zone (TAZ) for the Portland-Vancouver metropolitan area. Metro's work, performed on a subcontract basis for ICF Consulting, constituted the highway mobile source element of the Portland Air Toxics Assessment (PATA), a pilot project funded by the U.S. Environmental Protection Agency (EPA) in cooperation with the Oregon Department of Environmental Quality (DEQ). A longer version of this paper containing the referenced appendices is available at ftp://ftp.metro-region.org/dist/tran/tf/toxins/PATA_documentation.pdf

Figure 1 outlines the major tasks along with their inputs and outputs. This document explains these tasks in detail and concludes with a discussion of the applicability of these methods to other projects.

Figure 1. Project Flow Diagram

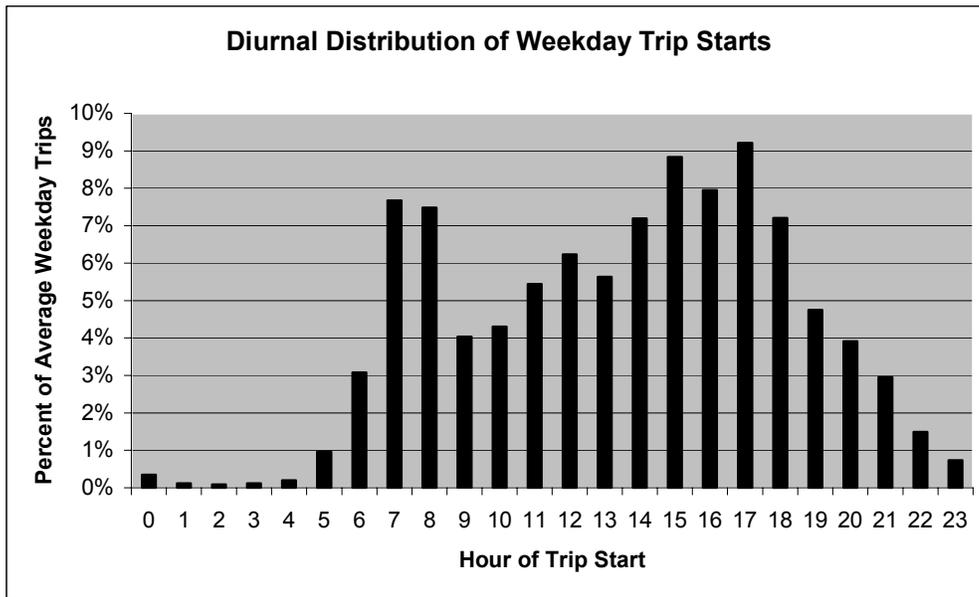


Diurnal Distribution of Trips

Trip generation, trip distribution, and mode share are performed on an all-day basis in Metro’s weekday travel model. (Metro does not have a weekend travel model.) As hour-by-hour emissions were needed for this project, it was decided to split all-day vehicle trips into several periods. The goal was to account for temporal variation in travel speeds while minimizing the number of required traffic assignments.

The periods were chosen based on local data: the trip start times for weekday vehicle trips reported in Metro’s 1994-95 household activity survey, as presented in Figure 2.

Figure 2. Vehicle Trip Start Distributions, Metro 1994-95 Household Activity Survey



The seven selected time periods are listed in Table 1. The objective was to assign the hours of the day to time periods with consistent path choice patterns.

Table 1. Time Periods

Period	Name	Times
1	Night 8 hours	22:00-05:59
2	AM 1 hour shoulder	06:00-06:59
3	AM 2 hour peak	07:00-08:59
4	Mid-day 5 hours	09:00-13:59
5	PM 2 hour shoulder	14:00-14:59, 18:00-18:59
6	PM 3 hour peak	15:00-17:59
7	Evening 3 hours	19:00-21:59

For each period, peaking factors by trip purpose were generated from survey data. These were applied to Metro’s 1999 all-day vehicle trip matrices to form the matrices to assign on the network. Each hour’s proportion of trip starts within its period was later used to determine the percentage of assigned volumes to apportion to each hour.

Traffic Assignment

All 26,089 one-way links in Metro’s modeling network were allocated to one of the five link types defined in the MOBILE documentation, as portrayed in Table 2. Emissions were modeled for the 24,553 links allowing vehicle traffic.

Table 2. Link Types

Ltype	Facility	Notes	No. of Links
1	Freeway		892
2	Arterial	all non-freeway, non-ramp roads in network	18,383
3	Local Roadway	TAZ centroid connectors	4,605
4	Freeway Ramp		673
5	Non-Street Link	no emissions (e.g. LRT, walk connector)	1,536

Volume-delay function files were built for each time period. Single-hour delay functions were applied to multi-hour periods by multiplying hourly link capacities by the number of hours in the time period. As the vehicle fleet age profile varies by county, the PATA project team decided to track emissions by county. All trips were allocated to one of the five fleets listed in Table 3 based on the trip production zone. Multiclass assignments for each time period were performed in EMME/2 using fleet-specific trip matrices, in order to track the emissions characteristics of the vehicles on each link.

Table 3. Vehicle Fleets

Fleet	County	Vehicle Inspection/Maintenance Program
1	Multnomah	Oregon (Portland)
2	Washington	Oregon (Portland)
3	Clackamas	Oregon (Portland)
4	Clark	Washington (Vancouver)
5	Non-I/M	zones outside I/M areas in any county

The data exported to the database consisted of a text file with passenger-car-equivalent (PCE) volumes for each unique combination of Period, Linkid, and Fleet. Also exported was a file containing the length, link type, and volume-delay function (VDF) for each link.

The EMME/2 macros used for this project are referenced in Appendix A.

Emission Rate Calculation

The advance version of the MOBILE 6.2 emission factor model was employed as it is the newest version of EPA's software to explicitly calculate emission rates for air toxins. Three of the project's toxins of interest were automatically generated by MOBILE upon invocation of the AIR TOXICS command. The others required an ADDITIONAL HAPS input file; this was built by Eastern Research Group and provided by EPA.

For freeways ("NON-RAMPS" in MOBILE) and arterials, the AVERAGE SPEED command was used to calculate emission rates for MOBILE's 14 average speed bins, which are centered on 2.5 mph and each 5 mph increment between 5 mph and 65 mph. Rather than treating the MOBILE results as emission lookup tables, the project team decided to build equations to calculate emissions at any speed; this is discussed in the next section. For local roadways and freeway ramps, MOBILE calculates emission rates based on a fixed speed, regardless of the speeds produced by the traffic assignment. The assumed speed is 12.9 mph for local roadways and 34.6 mph for freeway ramps.

The MOBILE default vehicle type distributions were used for all link types. MOBILE's composite ("All Veh") emission rates were used for all pollutants except diesel particulates.

The 27 pollutants of interest are listed in Table 4. Except where noted, emissions of each pollutant:

- vary by speed
- were generated based on total vehicle volumes
- were assigned entirely to running emissions

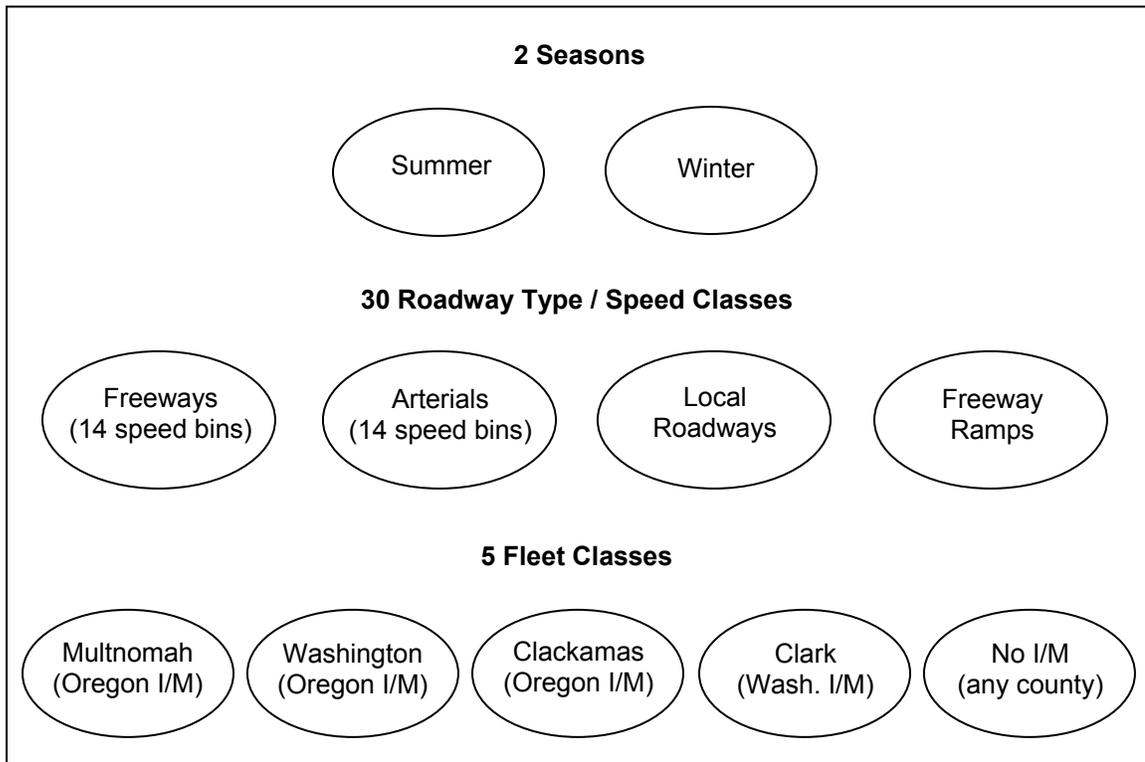
Table 4. Pollutants Modeled

Name	ID	Reference	Notes
Pollutants automatically generated by MOBILE 6.2			
Benzene	1,2	benzene	} have running and non-running emissions
1,3 Butadiene	3,4	butadien	
Formaldehyde	5	form	
Acetaldehyde	6	acet	
Acrolein	7	acro	
Elemental Carbon	28	ecarbon	} particulates generated based on diesel vehicle volumes; do not vary by speed
Total Diesel Exhaust P.M.	29	totdpm	
Name	ID	Reference	Notes
Toxins requiring use of ADDITIONAL HAPS inputs			
Chromium (Cr6)	8	chrom6	} emissions do not vary by speed
Chromium (Cr3)	9	chrom3	
Nickel	10	nickel	
Arsenic	11	arsenic	
Acenaphthene	12	acenene	} <u>Polycyclic Organic Matter (POM)</u> POM toxins of concern consist of these 16 Polycyclic Aromatic Hydrocarbons (PAHs). *Emissions of Dibenz(ah)anthracene do not vary by speed.
Acenaphthylene	13	acenyle	
Anthracene	14	anthra	
Benzo(a)anthracene	15	benzanth	
Benzo(a)pyrene	16	benzpyre	
Benzo(b)fluoranthene	17	benzbflu	
Benzo(ghi)perylene	18	benzogpe	
Benzo(k)fluoranthene	19	benzkflu	
Chrysene	20	chrysene	
Dibenz(ah)anthracene*	21	dibenz	
Fluoranthene	22	fluoran	
Fluorene	23	fluorene	
Indeno(123cd)pyrene	24	indeno	
Napthalene	25	naptha	
Phenanthrene	26	phen	
Pyrene	27	pyrene	

County-specific fleet age profiles for 1999 were obtained by DEQ from Oregon and Washington state vehicle licensing records. DEQ and the Washington Department of Ecology provided the MOBILE inputs for the inspection/maintenance programs and fuel types. The same winter and summer temperature and humidity readings were used for all parts of the region.

For each season (summer and winter) and the five fleets, MOBILE was run 30 times: at the 14 average speed bins for freeways and arterials and once each for local roadways and freeway ramps. The resulting 300 scenarios, illustrated in Figure 4, were run in batch mode.

Figure 3. MOBILE Runs



The MOBILE input/output files and their associated scripts are referenced in Appendix A. A description of the MOBILE inputs is presented in Appendix B. Samples excerpted from the MOBILE output files are presented in Appendix C.

Speed Equation Regression

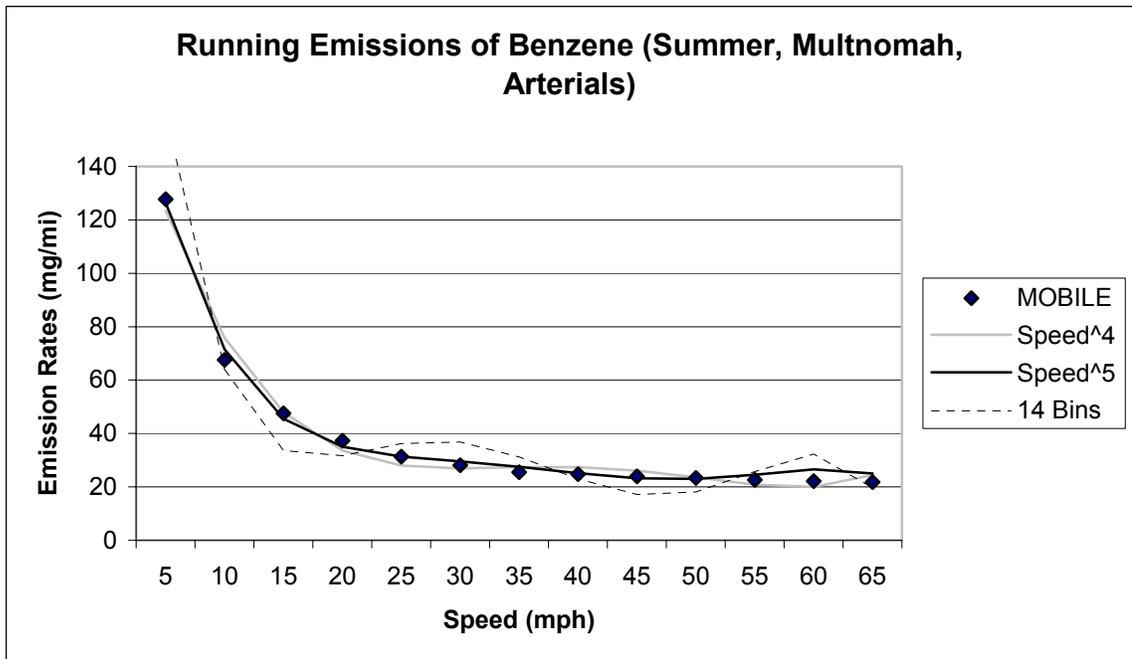
In MOBILE 6.2, emissions of most toxins vary by speed on freeways and arterials. The PATA project team decided to build equations that would estimate a link's emissions at any speed. The alternative, multiplying link VMT by the emission rate for the applicable MOBILE speed bin, was deemed less accurate for link-based modeling.

For each season-fleet-linktype-toxin combination, speed-emission curve equations were developed by linear regression using the 13 records for average speeds between 5 and 65 mph.

- Dependent variable: MOBILE emission rate
- Independent variables: Speed, Speed2, Speed3, Speed4, Speed5

This equation form was used as it produced the best fitting curve, as exhibited by the samples in Figure 4. The 2.5 mph record was dropped from the regression because the full 14 speed bins tended to produce distorted curves. For any link operating at a speed below 2.5 mph, MOBILE's 2.5 mph emission rates were applied directly to VMT. This is consistent with MOBILE's technical guidance on modeling emissions from idling vehicles.

Figure 4. Sample Emission Curves



In Figure 4, the markers represent the emission rates produced by MOBILE for running emissions of Benzene from a vehicle in the Multnomah County fleet on an arterial in summer. The lines present three samples of equations that were tested for ability to replicate these values. The curves for most toxins begin to approach the markers with the introduction of Speed⁴, but adding Speed⁵ brings the emission rates even closer, unless the full 14 bins are used. Here is the final equation chosen for the above example:

$$\text{Emissions} = 228.6648 - 26.8038 * \text{Speed} + 1.445543 * \text{Speed}^2 - 0.03829 * \text{Speed}^3 + 0.000489 * \text{Speed}^4 - 0.0000024 * \text{Speed}^5$$

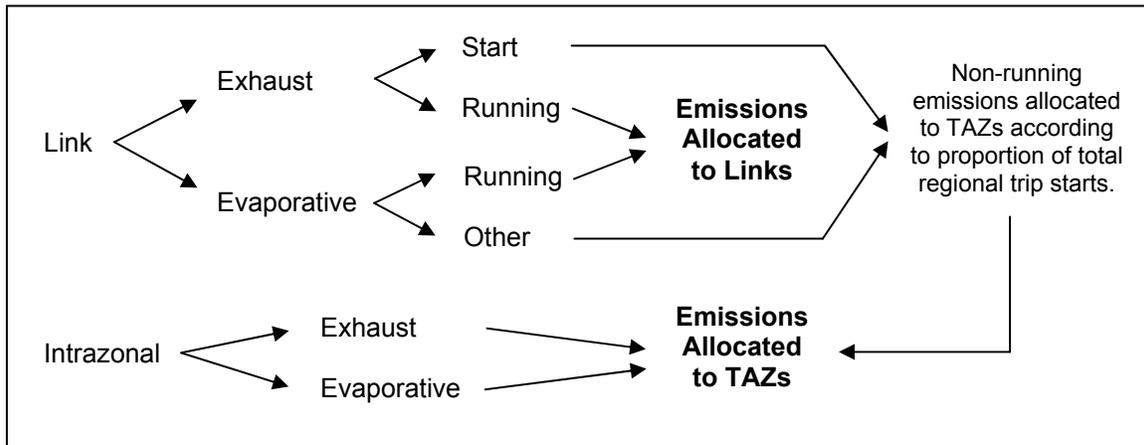
The regressions were performed in Stata due to ease of programming, as 440 equations needed to be produced to estimate emissions for all season-fleet-linktype-toxin combinations. The scripts used to create the equations are referenced in Appendix A.

Database Management

A database was required for the emission calculation due to the large number of records and the complexity of the queries. The work was begun in Microsoft Access, a tool available to all project team members. As the work progressed, it became clear that even with repeated compacting of the database, it would ultimately exceed Access' 1 GB size limit. So the tables and queries were transferred to Oracle. The queries ran on a Linux node with 6 GB RAM and two processors of 1.2 GHz each. The project eventually required 10 GB of Oracle tablespace.

The emission calculation steps for Benzene and 1,3 Butadiene are summarized in Figure 5. All emissions of the other pollutants were considered running exhaust per EPA staff. No link emissions for those pollutants were reallocated to zones.

Figure 5. Allocation of Benzene and 1,3 Butadiene Emissions



The steps of the emission calculation process are described in sequence below. The input and output tables are described in Appendix D.

Calculation of Hourly Volumes

Four conversion factors were needed to prepare the fleet-specific volumes from the EMME/2 assignments for the emission calculations.

- Volumes from the seven assignment periods were apportioned among the periods' constituent hours, using trip start factors from Metro's 1994-95 household activity survey. These factors are listed in Table 5. The AM shoulder period, composed only of Hour 6 (06:00-06:59), did not require a factor.

Table 5. Hourly Proportion of Trips within Time Periods

Night		AM peak		Mid-day		PM shld		PM peak		Evening	
Hr	Factor	Hr	Factor	Hr	Factor	Hr	Factor	Hr	Factor	Hr	Factor
0	0.093	7	0.551	9	0.163	14	0.481	15	0.300	19	0.412
1	0.033	8	0.449	10	0.171	18	0.519	16	0.321	20	0.324
2	0.025			11	0.206			17	0.379	21	0.264
3	0.034			12	0.240						
4	0.064			13	0.221						
5	0.279										
22	0.306										
23	0.166										

- The EMME/2 assignments included trucks in passenger-car-equivalent (PCE) units. These needed to be converted into total vehicles. The project team decided to apply MOBILE’s default percentage of heavy vehicles (9.8%) to every link. The number of vehicles on each link was thus calculated in the following manner:

$$90.2\% \text{ of Vehicles} + ((9.8\% \text{ of Vehicles}) * (1.7 \text{ PCE factor})) = \text{PCE}$$



$$\text{Vehicles} = \text{PCE} / 1.0686$$

- The number of diesel vehicles was required for the calculations of elemental carbon (ECARBON) and total diesel particulate matter (TOTDPM). This was estimated by multiplying the calculated vehicle volumes by 0.07207. This figure also was derived from MOBILE defaults.
- Metro’s model represents travel on an average weekday in May. The summer emission factors were applied directly to the model output, as modified above. A winter adjustment factor was developed by comparing total Monday-Thursday traffic counts at seven freeway recorders on two non-holiday weeks in both February and May 1999. Summer volumes were divided by 1.09534 prior to application of the winter emission factors.

Calculation of Hourly Speeds

Total PCE volumes (all fleets) for summer and winter were maintained for the speed calculations on freeways and arterials. Metro’s conical volume-delay functions (the same used within the EMME/2 assignments) were translated into SQL to calculate link speeds for each hour.

Calculation of Link-Based Emissions

All hourly emissions from vehicles were first generated at the link level. (The one exception is intrazonal trips, which are discussed in the next section.) This involved several sets of calculations:

- The emission rates from MOBILE were applied directly to total VMT for:
 - freeway and arterial links with speeds below 2.5 mph.

- local roadways and freeway ramps, which have hard-coded speeds in MOBILE.
- those toxins whose emissions do not vary by speed.
- The speed-emission curve equations were applied to total VMT for freeway and arterial links with speeds above 2.5 mph.
- The emission rates for the diesel pollutants of interest (ECARBON and TOTDPM) were applied to VMT from diesel vehicles.

Calculation of Intrazonal Emissions

Intrazonal trips, which start and end in the same TAZ, account for 1% of total regional VMT. These trips were not assigned on the network, but their emissions still needed to be captured. Within EMME/2, intrazonal VMT for each period was calculated by multiplying intrazonal trips by a matrix of average intrazonal trip distances. Within the database, these PCE VMT values were expanded out to total vehicle and diesel VMT by season and hour in the same manner used for the links. As all intrazonal travel is assumed to take place on local roadways, the local roadway emission rates were applied to intrazonal VMT.

Calculation of Zone-Based Emissions

Zone-based emissions are composed of the non-running components of Benzene and 1,3 Butadiene, plus intrazonal emissions of all pollutants (discussed above). The following methodology was developed to assign non-running emissions from links to the TAZs in which they originate.

Emissions of Benzene and 1,3 Butadiene on links were tracked by their running and non-running components through the use of separate emission curve equations. Following is a list of those emission components considered non-running:

- start exhaust emissions
- hot soak evaporative emissions
- diurnal evaporative emissions
- resting evaporative emissions
- refueling evaporative emissions

The evaporative emission factors, which apply to Benzene only, were output by MOBILE in the .TOX files. The portion of exhaust emissions to assign to starts was estimated by the algorithm described below. The remaining exhaust emissions (plus running evaporative emissions of Benzene) were assigned to running emissions. All pollutants other than Benzene and 1,3 Butadiene were assigned completely to running emissions. All interzonal running emissions were assigned to links.

MOBILE 6.2 does not output start emissions for air toxins. Following a recommendation from EPA staff, the ratio of VOC start emissions to VOC total exhaust emissions was extracted from each MOBILE scenario. This was accomplished by applying the following formula across the six vehicle types that contain both VMT distribution and

start emission factors in the .TXT output files (LDGV, LDGT12, LDGT34, LDDV, LDDT, and MC).

$$\sum (\text{VMT Distribution} / \text{VOC Start} * \text{VOC Total Exhaust}) / \sum (\text{VMT Distribution})$$

Applied to the example .TXT file in Appendix C, this equation takes the following form:

$$\begin{aligned} \% \text{ Start} = & ((0.70 / 1.16 * 0.5909) + (0.55 / 1.06 * 0.2256) + (0.98 / 1.87 * 0.0779) \\ & + (0.44 / 1.14 * 0.0021) + (0.70 / 1.53 * 0.0014) + (0.42 / 1.66 * 0.0040)) / \\ & (0.5909 + 0.2256 + 0.0779 + 0.0021 + 0.0014 + 0.0040) = 0.573148 \end{aligned}$$

This percentage start value was applied to exhaust emissions of Benzene and 1,3 Butadiene for each combination of fleet, season, link type, and speed. The resulting values, added to the non-running evaporative emissions described above, formed the emission rates that were used to calculate non-running emissions on links.

The total number of vehicle starts by zone and period was calculated from the EMME/2 trip matrices. These data were used to generate, by period, each TAZ's percent of regional trip starts. These proportions were applied to the periods' corresponding hours. The regional total non-running emissions of Benzene and 1,3 Butadiene were apportioned among the zones according to these zonal proportions. To these were added the intrazonal emissions of all pollutants.

Calculation of Total Emissions

Two data conversions were applied to the output tables:

- Emissions of the 16 PAHs were summed to form POM (Polycyclic Organic Matter).
- The diesel particulate emissions were converted from grams to milligrams.

Emissions of all pollutants were reported in milligrams.

Summary tables were created to contain regionwide total emissions for summer and winter. These totals were within reasonable range of data from less disaggregate sources, according to PATA study team members.

Applicability of Methods

The database structure and associated scripts developed for this study will be useful in future emissions modeling work at Metro, including transportation conformity determinations. Other planning organizations should note that the same basic approach could be adapted for local conditions.

- Fewer time periods and fleets, if locally appropriate, could simplify the problem.
- MOBILE 6.2 is necessary for modeling air toxins, but other versions of MOBILE can be used for VOC, CO, and NOx.

Any traffic assignment, statistical, or database management software could substitute for EMME/2, Stata, and Oracle. In fact, the PATA database work was begun in Access, but the problem size forced the transfer to Oracle.

Ridership Forecasting for Light Rail New Start: Updating the St. Louis Regional Model After Opening of the MetroLink Extension in St. Clair County, IL

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and Bruce Kaplan

Abstract. The St. Louis metropolitan area has expanded its successful light rail transit system known as MetroLink. The initial segment of MetroLink was opened in 1993 and ridership on this segment exceeded the forecasts. The first extension of MetroLink, which opened in May 2001, extends 17.4 miles east from East St. Louis to Southwestern Illinois College (SWIC). Multisystems prepared ridership forecasts for this extension during Preliminary Engineering in 1996 using the St. Louis regional demand forecasting model, maintained by EWGCC. At that time, Multisystems performed validation and re-calibration of the model to 1995-96 conditions on the original segment. Using the validated model, ridership forecasting was conducted for the project for the horizon year (2010) and the opening year (2001). Actual ridership on the new segment in 2001 was about 6% greater than the forecast. In Fall 2001, Multisystems was asked to prepare forecasts for a second phase MetroLink extension to the east of SWIC. A re-validation to 2001 conditions was incorporated in the new analysis. This paper discusses issues that arose in the validation effort and the subsequent ridership forecasting. These included developing a reliable estimate of observed ridership, handling special generators and special events, representing the fare free zone, reflecting work trip patterns of low income residents, eliminating short trips on transit, representing walk and park and ride access, and incorporating appropriate mode-specific constants coefficients in the mode choice model. It is hoped that the paper will aid in the creation of better light rail demand forecasting models.

The Base Model

The St. Louis regional travel demand model, maintained by the regional MPO (the East-West Gateway Coordinating Council) and run in MINUTP, has been revised several times since the early 1990s as a series of studies was conducted of MetroLink extensions in a variety of corridors. While this study attempted to maintain consistency with the latest version of the model (validated in the recent Cross-County MetroLink study and referred to as the “**Base Model**”), due to the following issues, further refinements were desirable.

- The Base Model used demographic projections made in the 1990s since the 2000 Census had not occurred.
- The transit networks did not reflect the severe cutback in its Missouri bus routes implemented by Bi-State Development Agency in the fall of 2001, when approximately one-third of its Missouri bus lines were eliminated.
- St. Clair County Transit District restructured all of its routes to serve as feeder buses to the county’s ten MetroLink stations, eight of which opened in May 2001.
- Commercial airlines no longer served Mid-America Airport in 2001. The Base Model used a projection from 1998 for service at Mid-America Airport
- The Base Model did not reflect MetroLink’s Midday Downtown Fare Free Zone.

- The Base Model was validated against 1998 MetroLink ridership figures, excluding the effect of the eight new Metrolink stations in St. Clair County which opened in 2001.
- A substantial rail-specific bias was introduced in the Base Model for all trips that use rail, including trips requiring a bus connection. When applied, the projected MetroLink ridership total was very close to the observed total MetroLink ridership. However, on a station-by-station basis, projected boardings were not close to the actual observed number of boardings.

Model Recalibration and Validation

Multisystems undertook the re-validation (and re-calibration) of the Base Model against the ridership and travel patterns observed in 2001 and early 2002 after service began on the St. Clair MetroLink extension to Southwest Illinois College. The process began by assembling the 2001/2002 observed data and updated land use and transportation inputs to reflect current conditions. Next, other aspects of the model that might be improved were identified. After discussing possible approaches with FTA officials and obtaining their comments, modifications to the model were made as part of a “recalibration effort.”

Model Adjustments

Model adjustments took place at various steps of the four step process.

Updated Inputs for Trip Generation

Inputs to trip generation were updated including land use and employment for all zones, unemployment rates by area, and characteristics of air travel and other special generators.

Land Use -- New land use data, based on the 2000 census, was provided by the MPO; new employment data was obtained from area municipalities and state employment agencies. The data was adapted to the zone system used.

Unemployment Rates -- The model adjusts the number of home-based work trips generated by each zone based on the respective area’s relative level of unemployment. These adjustment factors were updated based on Fall 2001 unemployment data for cities and counties maintained by the respective states.

Air Travel -- In the Base Model, Lambert International Airport and Mid-America Airport are treated as special generators and air passenger trips constitute a separate trip purpose. For this study, the volume of air travel at Lambert was updated to 15.3 million enplanements; other assumptions were maintained such as the share (47%) of air passengers that use ground-access to and from the airport (rather than just transferring flights). A further adjustment was introduced to constrain the number of trips to the airport for purposes other than work or taking an air trip. While the extensive retail activity at the airport is almost exclusively to serve the needs of travelers and employees already at the airport, the Base Model permitted airport retail activity to be a trip attractor for area residents.

Special Generators -- For other special generators in the model, updated information was obtained from the MPO. Specific attention was paid to Forest Park, Union Station, the casinos, the Convention Center, Scott Air Force Base and other key generators where the

model underestimated trip ends. Additional special generators were added as appropriate. The six categories of special generators are discussed briefly below:

- Universities and colleges—Colleges were already “special generators” in the Base Model. Home-based other and non-home based attraction trip ends (student trips) are based on enrollment data specifically entered in the trip generation routine, rather than from the land use input file. The revised model uses updated data on college enrollment.
- Hospitals and Clinics—Hospitals were also already included as “special generators” in the Base Model. The home based other and non-home based trips were based on information specifically entered into the trip generation routine to reflect the more intensive patient and visitor travel activity that this type of facility generates. Updated information on hospitals was obtained and several medical facilities were added as special generators. Furthermore, after consultation with the MPO, “public” employment in the MPO 2000 land use file was increased for several zones where medical facilities are located in order to account for the home based work trips that would be generated by these employers.
- Retail Centers and Shopping Plazas—The trip generation routine in the Base Model estimates trips to and from each zone for shopping purposes based on retail employment. Major retail plazas have a secondary agglomeration effect that yields a greater number of shopping trips than the standard trip generation rates would otherwise suggest. To account for this, the Base Model treated retail centers as “special generators.” The latest information from the MPO was used to ensure that shopping trips are distributed correctly around the region; note that the total attractions to retail for shopping purposes are not increased by these updates.
- Hotels— The St. Louis area has a large number of hotels that accommodate many visitors who were not being adequately represented in the Base Model. Based on a list from the St. Louis Convention and Visitors Commission of the metropolitan area’s largest hotels, along with their respective number of rooms, adjustments were made to the number of households in the land use input file. It was assumed that rooms would be 50% occupied and that for weekday travel they could be fairly represented as one-person households in the highest income tertile classification (most likely, business travelers). The adjustment added 5,592 trips in total.
- Scott AFB—Based on the latest data from Scott AFB, the number of households at the AFB was estimated to be higher than represented in the MPO land use estimates for 2000; an appropriate adjustment was made.
- Casinos and Recreational Attractions—The Base Model did not adequately account for the special attractions (chiefly tourist-oriented) that generate large numbers of trips in the St. Louis area. Since travel to these attractions is not included in METRO’s special event ridership counts and were not going to be treated as special events ridership, such travel needed to be included in the average-weekday non-special event estimate. An average weekday visitor figure was calculated from the annual visitor volumes obtained from the St. Louis Convention and Visitors Commission. This number was then added as an attraction in the TAZ in which the venue is located. Overall, 183,087 trips were added as a result of these attractions (amounting to 2.2% of the daily total trips). In addition to the visitors, we also increased public employment in Forest Park based on the MPO’s re-assessment of public employment there. Casinos and recreational

activities were unique in that trips were actually added to the underlying trip tables based on the attractions; for other special generators such as retail centers, the added attractions only served to redistribute trips that are generated and balanced to productions (thus maintaining the regional total).

Updates for Trip Distribution

In East St. Louis, Illinois, there are many low-income individuals who are located a short distance from downtown St. Louis. To reflect the lower likelihood that these residents would fill many of the white-collar jobs downtown, a k-factor was introduced to reduce this likelihood by 50% of that predicted by the distribution model for home-based work trips. The Base Model applied a uniform k-factor to all trips to or from Illinois, although it applied unique k-factors to numerous combinations of Missouri origins and destinations. Other than the change for the East St. Louis to CBD HBW trips, the k-factors in the Base Model were maintained.

Changes to the Mode Split Process

Adjustments to the constants in the disutility functions of the mode split process were made to yield a closer match to the observed behavior. As part of this adjustment process, the number of origin-destination groups was increased from 2 origin and 4 destination groups in the Base Model to 5 origin and 5 destination groups; the results is an increase from 8 to 25 combinations. To calibrate the model, a custom program was used to iterate until convergence between observed and modeled trips was achieved.

Although the Base Model's mode choice model is not nested (which would be a more theoretically sound approach), a conversion to a nested mode choice was not done; given the limited time available for the recalibration, FTA believed that other refinements should have higher priority. FTA also provided advice with regard to the use of a mode-specific rail constant. The FTA preferred that such a constant be a last resort. Attempts should be made to explain as much of the behavior as possible without such a constant first; only afterward should a mode specific constant be introduced if needed to match observed behavior. FTA also suggested that such a constant be applied only to "pure" MetroLink trips, that is, rail trips that did not require use of a bus for access or egress. After one hundred runs of the model to achieve the best fit, such constants were found to be necessary and were added. The validated model applied distinct MetroLink biases for each of the three income groups to rail trips that do not also use buses. Also, the rail biases were theoretically sound (e.g., higher for higher income).

Changes to Transit Networks and Path-building

Besides updating all transit routes and fares to 2002 conditions, the following changes were made to networks and path-building procedures:

Short Trip Prohibition -- The Base Model permitted short trips on transit (i.e., with in-vehicle travel times of less than 2 minutes) that in reality are generally made on foot. . These trips are mostly in the CBD where the small zone size makes these trips interzonal and thus are assigned to the network. The model assigns them to transit rather than automobile because the "terminal" times and costs (for parking, etc.) in the CBD are prohibitive. The revised model shifted them onto the downtown walk network.

Transit Walk Access -- The Base Model included an automated procedure to estimate the share of every zone's productions and attractions within walk distance of a transit stop. This share procedure avoids the need to manually estimate walk access each time the transit system is changed. The drawback is that the estimate is based on total zonal area (even if largely vacant) and does not necessarily reflect the actual distribution of zonal production and attractions. At Southwest Illinois College, the automated procedure for estimating the share of the zone within walk access of transit calculates only 40 percent even though in reality, the MetroLink stop is adjacent to the college. To account for this discrepancy and others affecting zones with large areas, manual adjustments were applied to the automatically-generated shares for zones with significant undeveloped land.

Transit Park-and-Ride Access -- The model defines which zones are accessible to each transit park-and-ride facility. The recent survey of riders on the St. Clair MetroLink extension shows that riders are choosing park-and-ride lots other than those modelers had originally expected. Park-and-ride access areas were revised accordingly and park-and-ride access directly to local buses was precluded.

Downtown St. Louis Fare Free Zone -- MetroLink operates fare-free between 11:30AM and 1:30PM for travel in downtown St. Louis (between Laclede's Landing and Union Station). The model was modified to account for this.

Validation Results

The following section describes the results of the validated model compared to observed data. An analysis of MetroLink ridership data was conducted to develop a base "observed" average weekday ridership estimate that was used in calibrating the ridership estimation model and also provided a factor for expanding average weekday ridership to full year ridership. Note that the comparison of the observed and modeled data is for non-special event travel only. Major special events from the observed ridership in accordance with METRO practice and special events activities are not included in the inputs to the model. Travel for special events is handled separately, as described in Section 3. The comparison for transit is made in terms of MetroLink station boardings and parking lot use, and bus boardings. Model validation also includes a comparison of highway volumes and a comparison of the home-based work trips against actual commute patterns identified in the 1990 census, since the 2000 Census journey to work data is not yet available for the St. Louis area.

Overall transit results

The average, non-special event weekday transit (MetroLink and bus) boardings in the modeled region total 161,913. The comparable model estimate is 164,076 in the validated model. Compare this with 178,977 using the Base Model (when applied with current inputs). The validated model estimate is within 1.3% of the observed amount compared to 10.5% for the Base Model. The results by mode (MetroLink, METRO Missouri bus, St. Clair bus, Madison County bus) show that the model yields a good fit overall to non-special event transit demand.

MetroLink boardings

For MetroLink boardings, the estimate is within 0.7% for the validated model (46,948 estimated compared with 46,612 observed). This compares to 13.8% for the Base Model applied to the same conditions (53,062 estimated compared with 46,612 observed). Note that the Base Model was validated on earlier data at a time when MetroLink operated only as far east as 5th & Missouri (prior to the extension to Southwest Illinois College). In addition to overall boardings, the re-validated model yields a good fit on a station-by-station basis (see Figure 1).

The re-validated model estimates ridership within 25% of the observed counts for 20 of the 27 stations. The model overestimates ridership by more than 25% at UMSL North, Grand, and Stadium; it also underestimates ridership by at least 25% at Lambert East, UMSL South, Laclede's Landing and Memorial Hospital. It should be noted that while some stations are too high, in some cases, a neighboring station is too low. For example, while UMSL North is 267 riders high, UMSL South is 567 riders low, so the net deviation for the two UMSL stations combined is only 12% or 300 low on a base of 2,551. Perhaps it is more reasonable to examine ridership by station group rather than by individual station in order to assess the overall model performance. Stations were grouped as follows: Lambert Airport, Missouri non-downtown, downtown, western St. Clair and eastern St. Clair (East St. Louis). Performance of the model is much better on this basis. Boardings in non-downtown Missouri, downtown St. Louis and eastern St. Clair all are within 1%; the airport stations combined are within 3% and western St. Clair within 5%.

Access to MetroLink stations

The model distinguishes how MetroLink riders arrive at and depart from stations – by walking, by bus or by automobile. Predicted automobile access was compared to a count of vehicles parked at Illinois MetroLink stations on several weekdays during November 2001; for Missouri stations where parking lot usage counts were unavailable, we have used parking capacity for comparison. Figure 2 shows how these counts compare with estimates of riders using auto access from the model. One column highlights the difference between the model and the count of parked cars or parking spaces. Another column expresses the difference as a ratio. Either way, it is an imperfect comparison due to the lack of count information in Missouri and because the counts in Illinois may underestimate the number of passengers boarding by automobile access. They may have missed some turnover of vehicles parked at the stations, and this may underestimate the number of vehicles parked. Note too that some auto access riders carpool or kiss-and-ride, so the differences between the observed cars or parking spaces and modeled auto access boardings may be less than that shown in the table or graph. Overall, the ratio is 1.12, which is reasonable considering the factors mentioned above. East Riverfront is one location where the re-validated model did not replicate observed behavior very well. Not only were more drive access trips attracted in the model to the East Riverfront station than were actually observed, but the number of modeled trips greatly exceeded the station's parking capacity. One explanation is that the model perceived the East Riverfront station as more attractive than travelers do and shifted trips from other nearby stations to the East Riverfront station. Indeed, the nearby 5th and Missouri and Emerson Park MetroLink station were under-predicted in terms of park-and-ride access; the Emerson Park station was under-predicted by several hundred drive-access trips.

Bus boardings

The validation model predicts bus boardings within 1.6% for the entire system and for METRO Missouri buses, within 1% for the St. Clair Transit District and 2.9% for Madison County (IL) buses. Within the Missouri bus routes, local buses are within 2.2% but express bus routes are underestimated by about 20% in total. The model is not able to replicate all individual bus routes within a reasonable tolerance and several are far off.

Figure 1: MetroLink Boardings By Station Re-Validated Model Estimate vs. Observed

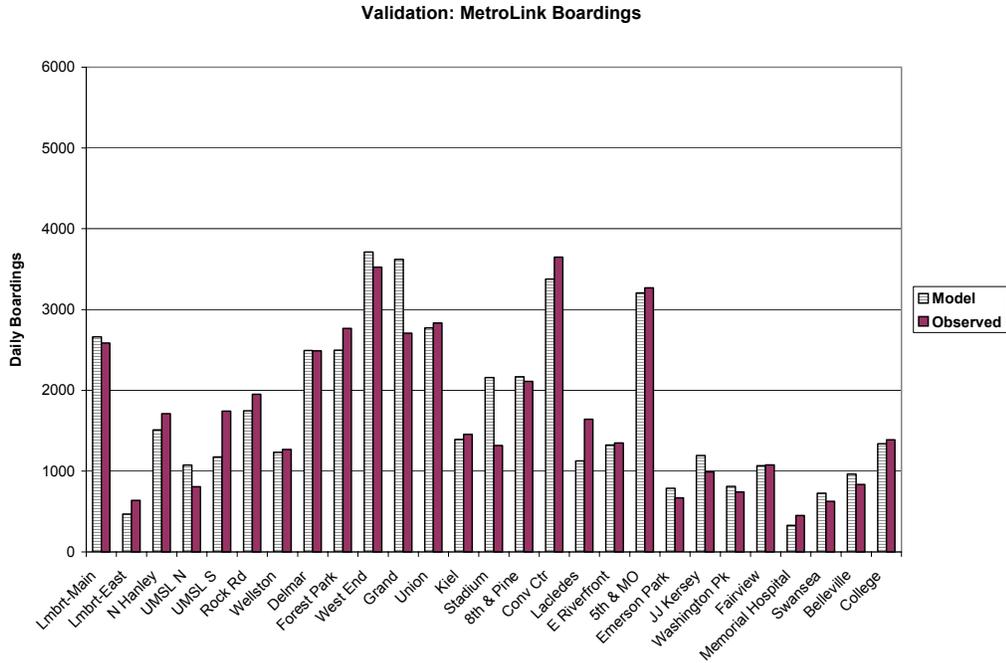
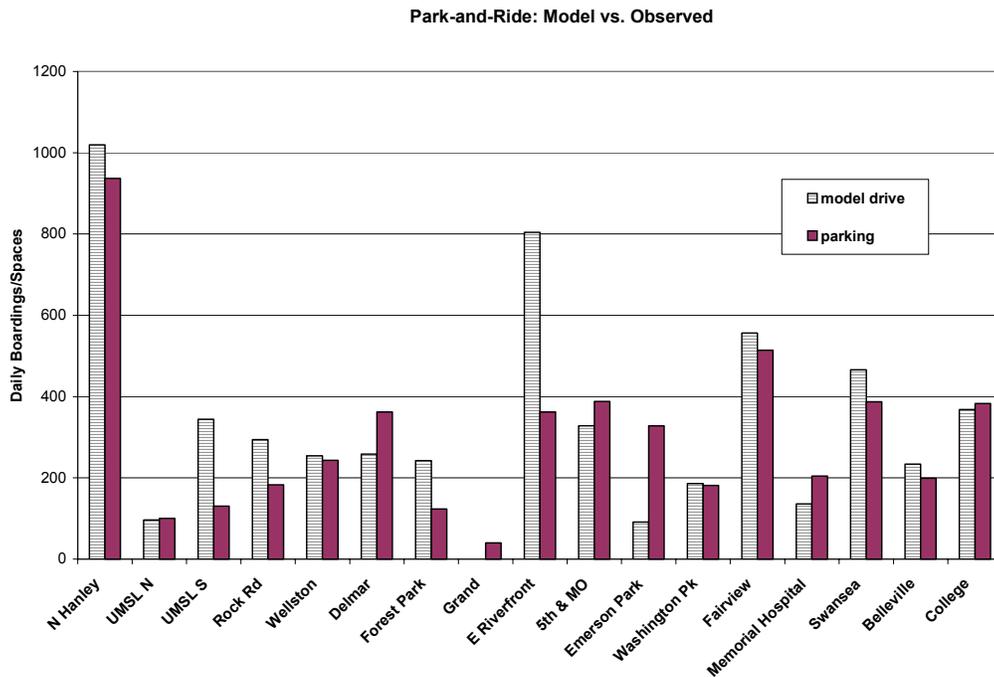


Figure 2: MetroLink Park-and-Ride Boardings By Station Re-Validated Model Estimate vs. Observed



Other measures

The distribution of commute trips is reasonable with regard to the most recent journey-to-work census data available (1990). All of the shares are within a few percent of the census findings, and the differences were what we might expect from land use and economic changes over the past ten years. Modeled and actual volumes are fairly close for most of the tested links.

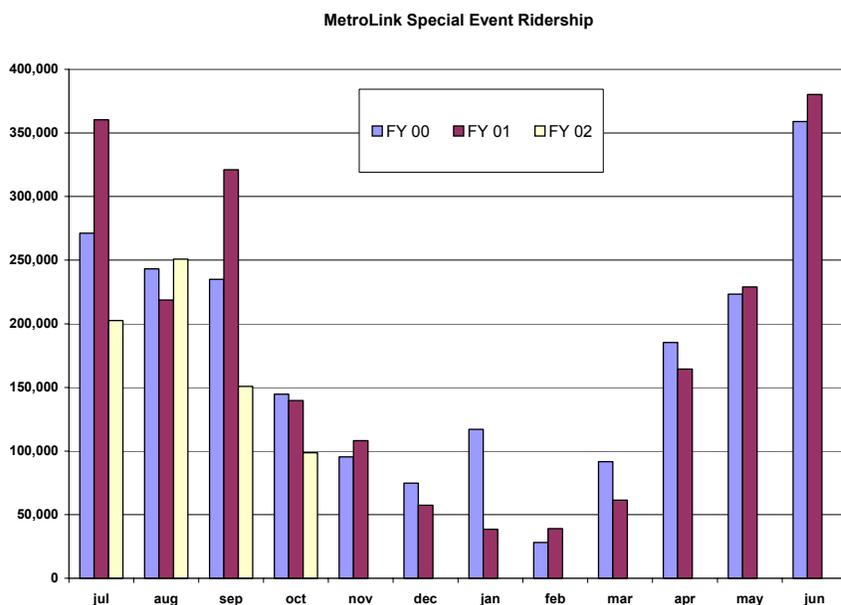
Special Event Methodology and Validation

This section describes the validation of the method used for special events ridership forecasting developed by Multisystems in consultation with FTA, METRO and SCCTD.

Background

Special events ridership constitutes a significant share (14.8%) of riders on the Metro Link light rail system. In FY2001, METRO recorded 2.11 million MetroLink boardings for major special event purposes; this compares with a total MetroLink ridership of 14.29 million. Event ridership is highly seasonal as shown in Figure 3. The four largest event types were the major sports events and one convention --Cardinals baseball at Busch Stadium (62.6%), Rams football at the American Airlines Dome (8.9%), Blues hockey at the Savvis Center (8.7%) and the Evangelical Lutheran Convention at the Dome (8.0%). All other events largely at the Savvis Center and the Dome contribute the remaining 12% of trips but no single event type accounts for more than 1.5%, except for Fair St. Louis in downtown (4.25%). While Illinois accounts for 22.7% of total special event MetroLink boardings and presumably a higher percentage of total productions (since many Illinois riders board in Missouri on their return trip), Illinois is reported to contribute about 50% of the riders for major special events.

Figure 3: MetroLink Special Event Ridership by Month and Fiscal Year



In the New Start study conducted in 1996 for the St. Clair County MetroLink Extension, which resulted in FTA approval of the construction of an extension to Southwest Illinois College (now in operation), Multisystems conducted an analysis of special events. This analysis was conducted “off-model,” utilizing METRO data on ridership at downtown special events to determine the impact of the extension on special event ridership. The impact of special events was estimated to increase the “new riders” for the build alternatives by 11% - 12%. For this study, an enhanced methodology was developed that addresses all major special event trips and clearly defines the origin location (zone) of these trips and their assignment to the travel network. It makes greater use of the model set recognizing that the mode choice functions in the model do not address and may not be appropriate for special events travel. A special events trip purpose was introduced in the model and separate model runs were conducted for each major type of event (e.g., football, baseball, hockey, other Dome events, other Savvis Center events, and the Scott AFB air show) using a transit network modified to reflect the conditions most likely to be in place during these special events.

Description of Method

Trip Generation

The first step was to estimate the number of trips attracted to each event by all modes. *Only* the special events for which METRO counts MetroLink ridership were considered since such ridership is excluded from the station-by-station estimates of METRO ridership used to validate the model described earlier. METRO provided counts of MetroLink *riders* for football, baseball and other major downtown events at the Savvis Center and the Dome. METRO also has counts of riders on special event buses for baseball and football games and on shuttle bus service connecting MetroLink riders to the Scott AFB Air Show. The estimated number of football and baseball attendees (traveling by all modes) for the past year is also available from METRO. Unfortunately, METRO does not have such estimates of the total markets for other large downtown events. However, annual estimates (for year 2000) of attendees at many of the major events available from the St. Louis Convention and Visitors Commission were used to establish the total attractions by event type. (See Table 1)

Trip Distribution

The second step was to determine how the attractions are distributed to production zones. (For simplicity, it was assumed that special event travelers originate at their home locations. In reality, some share of travelers may travel to an afternoon or evening event from a workplace. Another simplifying assumption was that all event attendees come from within the modeled region.) Lacking any data on the actual distribution of origins, a simplifying assumption was made -- distribution was based on population by income group. Because of the unique nature of these events and the fact that there are not multiple locations for these events, it did not seem necessary or appropriate to use a gravity model to consider the impact of travel time (or distance). Furthermore, since we have no information on the actual distribution of attendees, calibrating a gravity distribution model would have been impossible. Given the high price of tickets to professional sporting events, income probably plays the key role in determining the ability of individuals to attend these events and certainly more of a role than travel time or distance. In fact, given the higher incomes in the

suburbs, introducing a travel time variable might have yielded erroneous results. Thus, information on households by income tertiles was used as the basis for distributing trips to production zones. The number of households in each group was adjusted by a weight to account for the influence of income. The weighting was assumed -- the number of upper income households was boosted by 25%, the number of lower income households was decreased by 25% and the number of middle income households was not adjusted.

Table 1: Event Attendance and Transit Ridership

Event	Station(s)	Event Days/Year	Annual Attendance CY 2000	MetroLink Riders CY 2000	Special Bus Services				Estimated Mode Share		
					Missouri FY 2001	St. Clair past year	Madison FY 2001	Total Annual	Metro Link	Special Bus	Total Transit
Blues (hockey)	Kiel	43	981,737	150,688	NA	2,265	NA	2,265	8%	0%	8%
Cardinals (baseball)	Stadium	86	3,336,493	1,258,517	NA	14,132	4,246	18,378	19%	0%	19%
Rams (football)	Convention Center	12	518,302	225,703	23,470	8,873	2,796	35,139	22%	3%	25%
Scott AFB Air Show America's Ctr/Dome Events	College + shuttle/ Scott (future)	2	120,000	3,223	NA	3,607	NA	3,607	1.34%	2%	3%
Savvis Center Events	Convention Center	30	1,933,233	347,982	NA	NA	NA	NA	18%	0%	18%
	Kiel	79	974,750	175,455	NA	NA	NA	NA	18%	0%	18%

Event	Average Event Day			Average Day of Year		
	MetroLink	Special Bus	Total Transit	MetroLink	Special Bus	Total Transit
Blues (hockey)	3,504	53	3,557	413	6	419
Cardinals (baseball)	14,634	214	14,848	3,448	50	3,498
Rams (football)	18,809	2,928	21,737	618	96	715
Scott AFB Air Show	1,612	1,804	3,415	9	10	19
America's Ctr/Dome Events	11,599	-	11,599	953	-	953
Kiel (Savvis) Center Events	2,221	-	2,221	481	-	481

Note that the number of attendees at Dome and Kiel Center events (other than the sports events) was estimated assuming a mode share. Also note that a count shuttle bus riders between College Station and Scott AFB during the Air Show is used to estimate MetroLink ridership which is not otherwise counted for this event; these bus riders are omitted from the special bus ridership.

Mode Choice

The mode choice model was modified to reflect current special event travel behavior based on the available data. The mode choice logit model calculates mode share based on the combined disutility for each mode. The disutility is calculated as a weighted sum of several variables describing the time and cost of travel by each mode. There are also a series of constant terms in the disutility expression that vary by mode, by purpose, by income group and by major groupings of origin-destination locations. As part of the model validation for other trip purposes, adjustments were made only to these constant terms including a MetroLink-specific constant to fit the actual current travel behavior patterns better. A similar approach was taken to fit the observed travel behavior for special events given data on trip origin and destination, alternative modes and mode choice. Since there was no information on the actual origin-destination patterns of special event travel, the constant was assumed to be the same for all origin-destination pairs. Since mode shares to special events are high, the home-based work disutilities were used as the base upon which these adjustments were made; adjustments were made to fit the pattern observed for major events in the validation year for which the requisite data were available.

Trip Assignment

Finally, the special event trips made on transit were assigned to the transit network. The networks used for each major type of special event represent off-peak bus service conditions plus the special bus services operated during the specific type of special event. MetroLink headways were augmented to represent conditions typical of those during major special events (peak conditions). Parking costs were adjusted to reflect high parking costs on game days based on information supplied by METRO. The result of the assignment process was the number of boardings at MetroLink stations and on regular and special bus lines during special events.

Validation

Finally, using the best available information from the major events, the results were reviewed to determine if the model results were reasonable and adjustments were made as needed to better fit the information. The information available for comparison with modeled results included:

- Special event bus ridership (Redbird Express, etc.)
- MetroLink alightings at the venue station

The special event validation runs yielded a close match to the observed MetroLink special event boardings. The MetroLink boardings were within 0.1% overall and within about 1% by type of event except for the Scott AFB Airshow which was a small number of rail boardings and was within a few boardings.

Conclusion

Collection of new ridership count and survey information after opening of the MetroLink extension in St. Clair County enabled the St. Louis regional travel demand model to be updated to better reflect current travel behavior. The revised model was then used to examine the second phase New Start application. Besides updating the model inputs and using data on observed ridership, other improvements were made while maintaining overall consistency with the version of the model used in other corridor studies in the region.

Particularly important changes to the model included:

- Limiting the rail bias constant to rail-only trips after trying to explain behavior without a mode-specific constant
- Updating and refining information about special generators in St. Clair County and the region with specific attention to the activities at Scott Air Force Base, the proposed new terminus
- Consideration of tourist and special event travel including a method that uses the mode choice and assignment routines of the model rather than a completely off-model approach
- Refining the park-and-ride access to reflect actual behavior
- A fairer accounting for the impacts of weekend ridership on annual measures of new riders based on analysis of ridership count data.
- The special event methodology could be improved further if additional data on origins of special event travelers were available. While the lack of such information

did not have a major impact on the ridership results for this project, it probably has significant impacts on the model's robustness for other applications.

Acknowledgments

The authors wish to acknowledge the assistance provided during the project by Glen Griffin of East-West Gateway Coordinating Council, David Beal and staff at METRO, Jeffrey Bruggeman of AECOM Consulting and the staff at St. Clair County Transit District and the Federal Transit Administration.

Innovative Planning Tools to Address Title VI and Environmental Justice in the Planning Process

Charles Goodman, *Federal Transit Administration*; Malaika K. Abernathy, *Maryland-National Capital Park and Planning Commission*; Steve Strains, *Northwestern Indiana Regional Planning Commission*; and Scott Ericksen, *San Antonio-Bexar County MPO*

Abstract. The goal of Environmental Justice and Title VI of the Civil Rights Act is to ensure that services and benefits are fairly distributed to all people, regardless of race, national origin, or income, and they have access to meaningful participation. As the agency responsible for coordinating the regional transportation planning process, the MPO must make sure that all segments of the population have been involved with the planning process.

Three metropolitan planning organizations were invited to participate in a “Challenge Grant” program as part of the USDOT Metropolitan Capacity Building Program to develop innovative practices in considering the provisions of Title VI of the Civil Rights Act and Environmental Justice in the transportation planning process. These MPOs demonstrated strategies and efforts for ensuring and substantiating compliance with Title VI and EJ and outreach to impoverished and minority communities.

Learn how three MPOs have developed analytical tools to assess their Title VI/EJ planning process, enhanced their on-going public outreach efforts through an advisory committee and secured the help of transportation equity advocates and university officials in developing their public involvement strategies.

Methods, Measures of Effectiveness and Tools for Addressing Transportation Equity

Darrell L. Howard, AICP, *Street Smarts*

Abstract. Transportation equity and environmental justice have become synonymous terms used to describe the benefits and burdens of transportation decisions to low-income and minority populations. The Federal Highway Administration has attempted to provide guidance about how to apply environmental justice policies to ensure transportation equity in the planning process, focusing mainly on the public involvement process. However, there has been no real guidance on the development of measures of effectiveness and other tools to actually measure benefits and burdens of transportation decisions.

This paper will explore the incorporation of measures of effectiveness for transportation equity, and propose possible tools for assessing the benefits and burdens of transportation investments. These measures of effectiveness and tools will go beyond the public involvement process. In addition, this paper will discuss methods for improving the overall development of transportation plans especially as it relates to minorities and low-income populations in the decision making process.

Environmental Justice has been defined by several groups, government and non-government alike, and has come to mean different things to different people depending on their interests, desires, and needs. The most common use of the term has been, in the past, associated with the sites specific impacts of development. However, the definition most commonly used by government agencies is the definition provided by the U.S. Environmental Protection Agency. This definition is really more of a policy statement for how Title VI of the Civil Rights Act of 1964 (Black, Hispanic, Asian-American, Native American, Aleutian or Native of the American Pacific Islands) and low-income populations (households with median incomes below poverty-level as defined by the U.S. Department of Health and Human Services) should be considered in the decision making process and the assessment of potentially beneficial or harmful investments.

The U.S. EPA defines environmental justice as "the fair treatment for people of all races, cultures, and incomes, regarding the development of environmental laws, regulations, and policies."¹ In its application environmental justice policies have specifically focused on Title VI and low-income populations. Executive Order 12898, Federal Actions to Address Environmental Justice reinforces this application of environmental justice policy, as does U.S. Department of Transportation Order 5680.2 which mandates that

¹ United States Environmental Protection Agency, Office of Solid Waste and Emergency Response.
www.epa.gov/swerosps/ej/

specific steps be taken to address transportation equity with Title VI and low-income populations.

The context in which transportation plans are developed is ever evolving, and has become more sensitive to the needs of all users of the transportation system. Included in this evolution are considerations about populations that are traditionally thought of as being “underserved” by the transportation system or “underrepresented” in the decision making process. These terms are often used incorrectly, typically in the place of the definition of affected populations provided by Title VI and by U.S. DOT Order 5680.2 which references Title VI. Achieving equity in the distribution of transportation costs and benefits can be tricky, and the concept of transportation equity, which is itself a tool, can be confusing. This is particularly because in its application, transportation equity is often used to mean environmental justice. However, transportation equity is not exclusive to Title VI and low-income populations but instead focuses on a larger group.

Transportation equity is a conceptual tool whose methodologies are used to address environmental justice. Because of this limiting of scope for the purpose addressing environmental justice concerns, there has been a great deal of confusion about and debate over what populations are and are not to be considered in analyzing the equitable distribution of benefits and burdens of the transportation system. In addition, disagreement about what investments and decisions constitute equitable distribution has also emerged. The environmental justice regulations put forth by the U.S. Department of Transportation, along with the Environmental Protection Agency’s definition of how environmental justice matters should be approached, however, are very clear in identifying what populations should explicitly be considered for analysis in evaluations of transportation equity.

Considerations of the definition of equity are a different matter, and will typically be negotiated through the political process. Still, there is confusion over how exactly one would apply methods to address transportation equity as well as measure benefits and burdens in order to identify inequalities in transportation policy and investment. Of particular difficulty is how to measure the benefits and burdens for specific populations.

The U.S. DOT identified three fundamental principles that are more specific than the U.S. EPA’s definition of environmental justice, and are considered to be an inherent part of all transportation policies, particularly as they related to addressing the equity concerns of environmental justice populations. These principles are meant to assist practitioners in evaluating transportation policies, and form the base of support for transportation equity measures and tools. These principles state that environmental justices policies should:

- Avoid, minimize, or mitigate disproportionately high and adverse human health and environmental effects, including social and economic effects, on minority populations and low-income populations.
- Ensure the full and fair participation by all potentially affected communities in the transportation decision-making process.

- Prevent the denial of, reduction in, or significant delay in the receipt of benefits by minority and low-income populations.²

Transportation equity, as it is being used in this document, is meant to describe a combination of social and economic ideas that address the opportunities of transportation decisions and investments, measuring these opportunities by evaluating the benefits and the burdens they place on minority and low-income populations. In reality, there is no one correct way to assess equity, and whether or not it can ever be truly achieved has been, and will continue to be, a matter of intense debate.

Transportation equity measures and tools are meant to identify systematic patterns in the distribution of transportation benefits and burdens as well as provide enough information to decision makers so that they may determine what policies should be put into place to achieve mutually acceptable levels of equity. They are also meant to provide methodologies that will avoid systematic biases in the planning and decision making process. Transportation equity measures and tools should also seek to be objective in their approach and analysis, realizing that the information they provide will be considered from many different perspectives.

Todd Litman of the Victoria Transportation Policy Institute in Canada approaches transportation equity with the argument that transportation is really a measure of opportunity. He states that equity is based on how transportation is defined by users of the system. Using this concept, Mr. Litman explains that there are three distinct forms of transportation equity. They are:

- Horizontal Equity. The fairness of cost and benefit allocation between individuals and groups who are considered comparable in wealth and abilities
- Vertical Equity with Regard to Income and Social Class. The allocation of costs between income and social classes where transport is most equitable if it provides the greatest benefit at the least cost to disadvantaged groups.
- Vertical Equity with Regard to Mobility Need and Ability. The measure of how well an individual's transportation needs are met compared with others in their community.³

Ultimately, in order to address transportation equity as it relates to environmental justice, the opportunities of transportation investments must be evaluated according to the benefits and burdens that they place on minority and low-income populations. This begs the question, how does one define benefits and burdens? Michael Meyer and Eric Miller identify some of the general characteristics of benefits and burdens (costs), particularly as they might be used in an evaluation process. According to Meyer and Miller benefits and burdens will:

- Recognize the difference between real and economic benefits and costs
- Make a distinction between direct and indirect benefits and costs

² United States Department of Transportation, *Order 5680.2, April 15 1997.*

³ Todd Litman, *Evaluating Transportation Equity.* Victoria BC: Victoria Transport Policy Institute, November 1999.

- Identify the degree to which tangible and intangible benefits and cost are measured
- Identify benefits and costs that are internal and external to the study area
- Differentiate between users and nonuser benefits and costs
- Distinguish between total and incremental benefits and costs⁴

These characteristics provide a foundation for developing general inquiries that will enable practitioners to preliminarily identify benefits and burdens as well as orient them towards the types of issues that might be of consideration. When considering the benefits and burdens of transportation policies, decisions, and investments it is important to be aware of the types of inequities that may result. Recall that the definition of transportation equity states that transportation equity is a combination of social and economic ideas that address the opportunities of transportation decisions and investments, measuring these opportunities by evaluating the benefits and the burdens they place on minority and low-income populations.

The benefits and burdens that assess transportation equity typically focus on the distributional impacts of policies, decisions, and investments of transportation. According to Dr. Robert Bullard of the Environmental Justice Research Center in Atlanta Georgia, there is an inherent inequity present in transportation system's policies, decision-making processes, and investments. As Dr. Bullard points out, these inequities exist because of the unequal distribution of costs and benefits which in turn creates or aggravates other inequitable factors in the transportation system. These factors can be classified under one or more of three general categories of inequities:

- Procedural Inequity. Procedural equity speaks to the fairness and openness of the transportation decision-making process
- Geographic Inequity. Geographic equity reports on the spatial distribution of benefits and costs
- Social Inequity. Social equity relates the disproportionate impacts or burdens borne by environmental justice populations.⁵

Armed with an understanding that transportation equity is really a measure of opportunities, and these opportunities may themselves be measured by the benefits and burdens they impose on minority and low-income populations, inequities in transportation can be adequately addressed. In order to do this, a set of comprehensive measures and tools by which the overall transportation planning, decision making, and investment process needs to be developed so that the processes can become informed.

The Community Impact Assessment Reference developed for the Federal Highway Administration's Office of Environment and Planning lays out some basic guidelines on

⁴ Michael D. Meyer and Eric J. Miller, *Urban Transportation Planning 2nd Edition*. New York City: 2001. pp. 488-490.

⁵ Robert D. Bullard, Glen S. Johnson and Angel O. Torres, "Dismantling Transportation Apartheid," *Sprawl City*. Atlanta: 2000. p. 46

how to identify benefits and burdens in order to critically evaluate areas so that transportation inequities might be identified and mitigated. The guidelines stress the importance of being aware of all of the impacts of decisions and investments including the temporary, long-term, secondary, and cumulative effects. They also instruct that practitioners should use community goals to help identify impacts, reminding that open and honest communication will help facilitate the identification of both positive and negative influences, especially since these are also a matter of perception.⁶ The Community Impact Assessment Reference provides a list of questions that might be asked to identify impacts across a broad range of areas as well as a listing of tools that can be used to evaluate the severity of these impacts. Table 1 presents some of the questions raised by the Community Impact Assessment Reference document of which practitioners should be aware. The full listing of questions may be obtained from the Community Impact Assessment Reference document.

Table 1: Questions to Identify Impacts of Transportation Investments on EJ Populations

Impact Categories	Questions
Social and Psychological Aspects	
Changes in the populations	Will the project cause redistribution of the populations i.e. an influx or loss of population?
Isolation	Will certain people be separated or set apart from others?
Quality of Life	What is the perceived impact on the quality of life?
Physical Category	
Sounds	Will noise or vibration increase?
Air Quality	Will dust or odor increase?
Visual Environment and Land Use	
Aesthetics	Will the community's aesthetic character be changed?
Compatibility with Plans	Will actions cause incompatibility with community or local land use plans and zoning?
Land Use Patterns	Will new areas be opened to development? Will the action induce changes in land use and density? Will there be a loss of community amenities?
Economic Conditions	
Business and Employment Impacts	Will the action encourage businesses to move to the area, relocate to other locations, or close and leave?
Property Values	What is the likely effect on property values?
Mobility and Access	
Pedestrians and Bicycle	How does the project affect non-motorist mobility and access?

⁶ William Brock, Buddy Cunill, Steve Dockter, John Isom, Greg King, Judith Linsey-Foster, Donald Sparklin, and Barbara Stevens, *Community Impact Assessment: A Quick Reference for Transportation*. Prepared for the Federal Highway Administration, Office of Environment and Planning, in cooperation with Apogee Research and Parsons Brinkerhoff Quade Douglas, Inc. 2000.

Public Transportation	Is access to public transportation impacted?
Safety	
Pedestrian and Bicycle Safety	Will the project impact pedestrian and bicycle safety?
Crime	Will the project lead to increase or decreases in crime?
Public Services	
Use of Public Facilities	Will the action lead to or help alleviate overcrowding of public facilities?

Recall that transportation equity as related to environmental justice has a strong focus on the distributional impacts of transportation’s benefits and burdens. Measures of equity have a tendency to evaluate how benefits and costs are distributed across the population. Questions utilized in the development of these measures seek to identify:

- The travel activity patterns of different income and racial groups
- To what extent minority and low-income populations shoulder a disproportionate share of burdens of transportation investments
- To what extent minority and low-income populations share in the benefits of transportation investments
- How transportation investments are being spent across racial/ethnic categories and income levels.⁷

In answering these questions, specific measures of the benefits and burdens of transportation opportunities can be developed. It is from these measures that practitioners obtain specific data that will inform the decision making process. Examples of specific measures include:

- Identification of concentrations of minority and low-income populations
- The proximity of minority and low-income populations to transit.
- Car ownership rates by race and income
- The average age of automobiles by race and income
- Comparison of the types and conditions of bus stops by race and income
- Access to jobs by race and income
- Access to community amenities and quality of life amenities
- The frequency of transit service
- The number of destinations available by transit
- Proximity of housing to employment centers by race and income
- The number of bicycle and pedestrian accidents in minority and low-income communities
- Comparisons of financial investments by mode to the use of by race and income
- Comparisons of transportation investments by location to race and income-level

⁷ Michael D. Meyer and Eric J. Miller, pp. 500 – 501. Southern California Association of Governments, “Community Link 21, Regional Transportation Plan: Equity and Accessibility Performance Indicators,” published in *Transportation and Environment Justice Case Studies*, ed. United States Department of Transportation. Washington, D.C.: December 2000.

- Comparison of air-quality impacts of investments by race and income⁸

Tools to help evaluate transportation equity will assess data collected from specific measures. They will also help to improve the transportation planning and decision-making processes. In selecting an evaluation tool, the Community Impact Assessment Reference⁹ document suggests identifying specific approaches to conducting equity analysis. The three approaches identified are:

- Comprehensive
- Incremental and
- Comparative

The comprehensive approach gathers existing relevant data in order to examine and address transportation equity issues. This approach has benefits in that it is relatively quick and cost-effective. The incremental approach assembles information in pieces, answering specific questions and measures. These data are assembled bit-by-bit, each one building upon a previous piece of information. When enough information is assembled, a “picture” can be painted about how well transportation equity has been or is being addressed, and conclusions can be made. The comparative approach contrasts data in order to identify similarities and differences between the information in order to reach conclusions about transportation equity.

The specific measures of transportation equity identified previously can be evaluated using one of these three approaches. For example, an incremental approach might identify the frequency of transit service in low-income and minority communities, then build on the data by identifying the number of jobs that are directly accessible by the routes that serve these communities in order to paint a picture of the home-based work trips made by transit by this population. The comparative approach would take this same information and compare it to other populations within the service area in order to determine if low-income and minority populations have to make more transfers, travel further, or travel longer than their higher income, non-minority counterparts. In all of this, it is important to know whether or not data is available to conduct an analysis at all. Data may or may not exist depending on the investments made over time by agencies, both government and non-government alike, in the collection and maintenance of information.

Efforts such as the SMARTRAQ project undertaken by the Georgia Institute of Technology, the Atlanta Regional Commission - Atlanta’s Metropolitan Planning Organization, and the Georgia Regional Transportation Authority are rare. The SMARTRAQ project collected travel data for the regional travel demand model and made a special effort to increase minority and low-income populations’ representation in the travel survey samples. Research conducted by the University of Iowa’s Public Policy Center corroborates the rarity of this effort, and indicates that most jurisdictions lack the

⁸ Michael D. Meyer and Eric J. Miller, pp. 500 – 501.

⁹ William Brock, et.al., 2000.

data and the resources needed to collect the data and perform analyses of transportation equity does not, nor has it ever existed.¹⁰ Tools for collecting data include traditional surveys, aggregation of information such as the census information, state social service and employment databases, and the internet. New technologies such as the transit smart card, in-vehicle and personal geographic positioning satellite transponders, and digital pedometers, are tools that hold potential for use as data collection tools.

By far, the most powerful tool to date for evaluating transportation equity is the Geographic Information System (GIS). Its ability to spatially identify populations also makes it the ideal tool for identifying and comparing the benefits and burdens of transportation equity. GIS allow practitioners to address geographic inequities, as well as analyze data collected from measures to address social inequities. Like many of the tools used to evaluate other performance indicators, GIS requires an intense amount of data to be able to evaluate multiple measures of transportation equity. Figure 1 illustrates how GIS can be used to identify geographic inequities by evaluating the spatial distribution of transportation investments. Figure 1 demonstrates how data can be presented using a GIS.

Figure 1: Transportation Improvements by Income

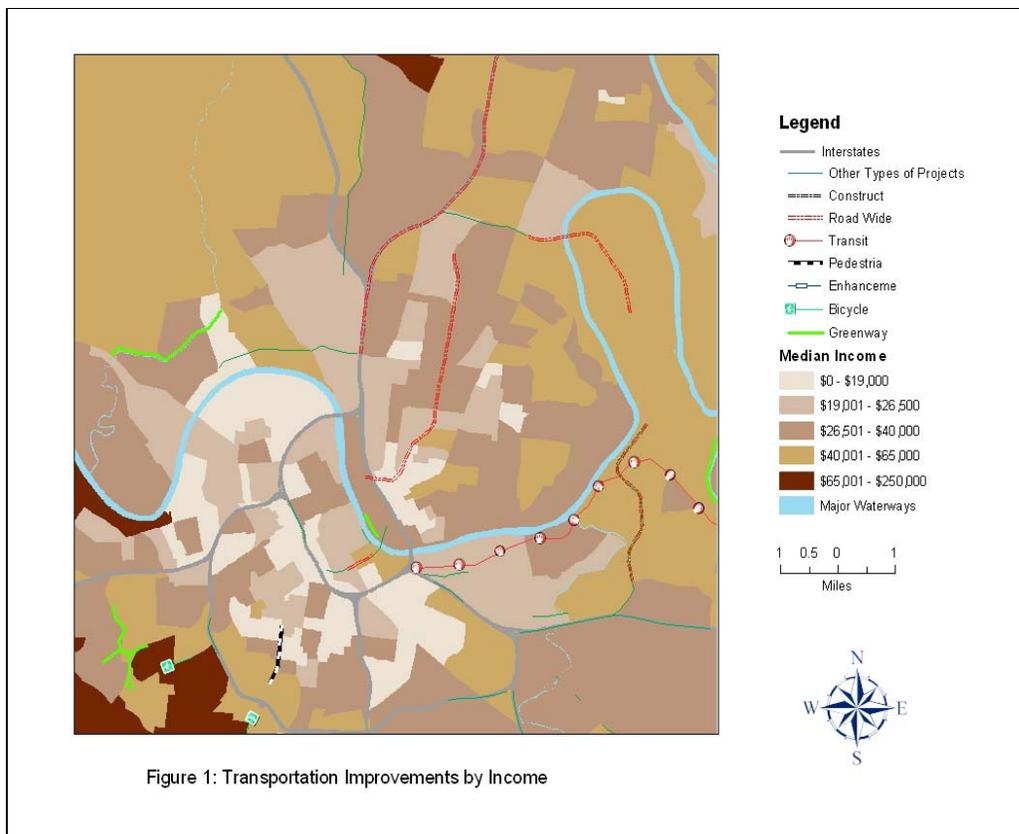


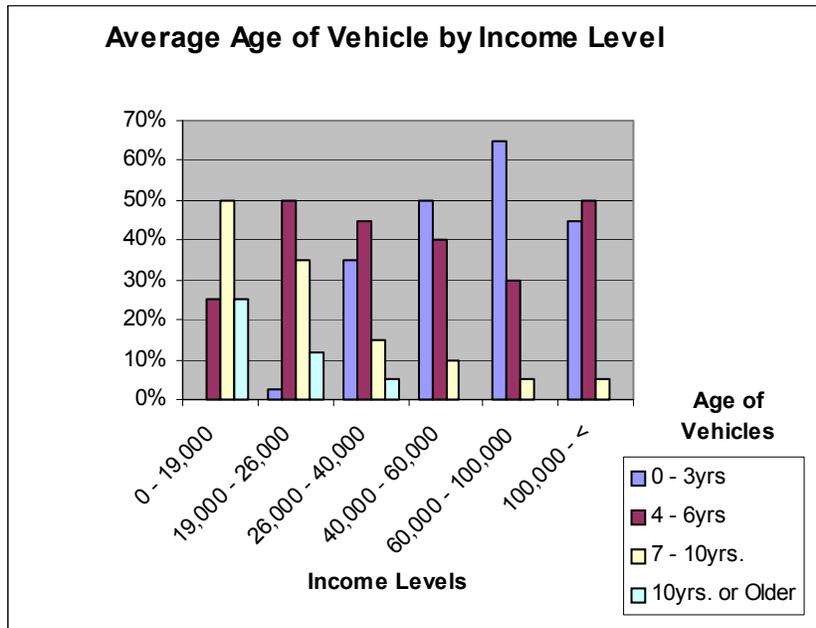
Figure 1: Transportation Improvements by Income

¹⁰ David J. Forkenbrock and Lisa A. Schweitzer, *Environmental Justice and Transportation Investment Policy*. Iowa City: University of Iowa Public Policy Center, 1997.

Statistics are another tool available to analyze transportation equity measures. Many of these tools are applied through the use of software such as Microsoft Excel and SPSS. These software packages can forecast data, create trendlines, and enable multiple measures to be analyzed in order to establish correlations and identify systematic inequities. Figure 2 shows how data might analyzed and displayed.

Public Participation is an often used, very effective tool when utilized correctly, to address procedural inequities. In addition, it can also provide the basis of information that can be measured to equity. For example, the number of minorities and low-income households represented at a series of public meetings taken as a percentage of the total number of minorities and low-income households within a study area can provide feedback on the effectiveness of an outreach effort.

Figure 2: Example of Statistical Analysis



Visual imaging tools may also be used to help convey messages and conduct preference surveys. These tools may include both physical models and drawings to illustrate concepts. However, advances in technology have enabled photographs of locations to be altered in real time, enabling the presentation of concepts in a “before and after” type format. In some cases, micro-simulation computer models such as the SimTraffic© software produced by Trafficware can be used to illustrate traffic operations concepts that look at a variety of transportation alternatives and enable input from minority and low-income populations about their preferred alternatives.

The creation and use of partnerships is yet another tool that can be utilized in addressing transportation equity. Representative groups for minority and low-income communities can be utilized to assist practitioners in a number of ways including, but not limited to, data collection, and public outreach. This was done in Atlanta for the SMARTRAQ project described previously.

The agencies conducting the project enlisted an environmental justice advocacy group to assist in the outreach effort for the collection of data of minority and low-income populations. Their role was simply to inform these populations that a survey was being conducted and to stress the importance of these populations participation. These latter tools of public participation and partnerships address the procedural inequities described by Dr. Bullard, and to some extent, enable specific data to be collected in order to evaluate and address geographic and social inequities.

In summary, there are a host of measures and tools by which transportation equity can be addressed, and in doing so, the main tenants of environmental justice met. Recall that transportation equity is a combination of social and economic ideas that address the opportunities of transportation decisions and investments. These opportunities are measured by evaluating the benefits and the burdens they place on minority and low-income populations and how well they address inequities. Transportation equity as it relates to addressing environmental justice concerns has a strong focus on the distributional impacts of transportation's benefits and burdens, and measures of equity have a tendency to evaluate how benefits and costs are distributed across the population.

An equity measure answers questions about the distributional impacts and can be used before, during and after policies, decisions, and investments are made. Most transportation equity measures focus on the generation of statistical information that may be evaluated using graphic tools. Others provide information on processes. Tools used to evaluate these measures are both graphic and statistical. Still other tools look to address transportation equity concerns by improving processes and establishing relationships.

Project Benefit Analysis: Proximity to Transportation Facilities is Not a Self-Evident Benefit to Those in Immediate Vicinity

Tracy Reed, *Central Puget Sound Regional Transit Authority*

Abstract. The USDOT Order on Environmental Justice was originally conceived to protect low income and minority neighborhoods from suffering disproportionate impacts from undesirable land uses. In Seattle, light rail project opponents have used the Order to challenge the impacts of a highly desirable light rail project. The irony is, some disruption to the community in terms of construction and property acquisition impacts is likely to occur in the process of bringing service to those who most need it.

Sound Transit's Link Initial Segment project will bring a new light rail line to the Seattle neighborhood that is home to a relatively high percentage of minority and low-income populations for the area. Our efforts focused on identifying and documenting the level of *benefits* Seattle residents will enjoy because of the rail project, including improved access to the region's largest employment centers, travel time savings, and access to health care and education. To our knowledge, no other light rail project has attempted to document these trade-offs in an EJ context.

Often, transportation projects are presented as mobility-improvements and so if there are notable levels of minority or low-income populations nearby the proposed improvement project then it's characterized as beneficial to those residents. GIS demographic analysis usually stops there. However this conclusion was not self-evident to many residents of Seattle.

GIS-based analyses of demographics, employment security department and travel forecast data were employed to examine three types of potentially offsetting travel benefits: (i) access to transit, (ii) travel time savings, and (iii) access to jobs, services, education and other opportunities. GIS and travel demand forecasting (EMME/2) software was utilized to define rail station travelshed zones around which travel time isochrones were defined to examine improved accessibility due to the project. The results showed not only that Southeast Seattle neighborhoods stand to receive greater than average transit travel time savings and job accessibility improvements, but that population-wide access to transit would be distributed among minority and low-income populations at a higher than average rate.

The paper / presentation may conclude with a status report on the Link project and legal challenges encountered by Sound Transit. The project development history that led to a route through Southeast Seattle; potential geographic correlation of low income and minority populations with low density urban form; and systematic constraints (i.e. topography and arterial congestion) on transit travel times are ripe areas of discussion for the audience.

Monte Carlo Simulation of Household Travel Survey Data with Bayesian Updating

Sirisha Kothuri, *Texas Transportation Institute*; Peter Stopher, *Louisiana State University*; and Phillip Bullock, *Institute of Transport Studies*

No abstract available.

Using a Multi-Mode Survey Strategy to Capture Highly Mobile Households in Household Travel Surveys

Heather Contrino and Johanna Zmud, *NuStats*

Abstract. This paper analyzes the impact of using both CATI and Internet to ensure a representative sample of trip-makers in household travel surveys. Modeling procedures in transportation planning depend on the quality of estimates of trip-making at the household and person levels coming from data collected in household travel surveys. Major surveys collecting data on household travel behavior in the U.S. have used computer-assisted telephone interviews (CATI). A major disadvantage of the CATI technique is that it relies on interviewer capability to make contact with a potential responding household. Previous studies have indicated that the number of calls required to make contact with potential respondents has grown substantially in the last several years (Groves and Couper, 1998). Many travel behavior researchers have hypothesized that the more mobile households in the RDD frames are those least likely to participate in CATI-administered travel behavior surveys because the most productive window of interviewing opportunity (5pm to 9pm) is a timeframe in which mobile persons are inaccessible to CATI interviewers.

Data from household travel behavior surveys in Los Angeles and St. Louis will be used to assess the effects of mode of survey administration on estimates of trip-making at the household and person levels.

Comparisons of the CATI and web estimates will be made overall for persons and households and within age, gender, educational level, employment, household income, and household composition subgroups. The analysis will disaggregate CATI data into households that required refusal conversion as well as those that required more than five calls for first contact. To assess the likelihood of reporting trips using CATI versus web, logistic regression models will be utilized controlling for possible confounding and interaction variables.

Texas Border Crossing Travel Surveys: Overview of Survey Methods, Results and Lessons Learned

Edwin Hard, AICP and David F. Pearson, PhD, P.E.,
Texas Transportation Institute

Abstract. In 2001, the Texas Department of Transportation (TxDOT) conducted travel surveys at various border crossings around the state's perimeter. The surveys were performed as part of a comprehensive 'Texas Border Crossing Travel Survey' project under the direction of TxDOT's Transportation Planning and Programming Division. The Texas Transportation Institute (TTI) assisted TxDOT with the survey's conduct and data analysis.

The project was made-up of four separate data collection efforts. The efforts included a state-to-state survey at border crossings with Texas' neighboring states, a Texas-Mexico survey at border crossings with Mexico, and two surveys for highways with high traffic volumes moving between Texas and its adjoining states. The purpose of the surveys was to collect information needed for a statewide travel analysis model being developed for TxDOT. The surveys collected information on trip characteristics of non-commercial and commercial traffic entering, exiting and passing through the state.

Three types of survey methods were utilized in the surveys. A roadside interview method was utilized to survey non-commercial and commercial vehicles on highways with low to moderate traffic volumes. For safety reasons, a license plate match and mail method was used to survey non-commercial vehicles on high volume facilities. Commercial vehicles on high volume highways/interstates were surveyed using a personal interview method at commercial truck stops and rest areas.

This paper will describe the survey methods and procedures used in the conduct and analyses of the Texas Border Crossing Travel surveys and discuss the problems, challenges, and lessons learned as part of the 6 month data collection effort. The preliminary results of the surveys showing the estimated amount and characteristics of traffic crossing the state's border on a daily basis will be presented. Results for non-commercial and commercial vehicle traffic as well as comparative results for Texas' border crossings with Mexico, New Mexico, Oklahoma, and East Texas will be included. The paper will present findings on the characteristics of Texas' border crossing traffic such as average trip length, trip purpose, and the percentage 'local' verses 'through' trips, and commercial vehicle cargo.

Estimating the Effects of a Commuter Fringe Benefit Program

Thomas Adler and Stacey Falzarano, *Resource Systems Group*; and
Reed Bergwall and Shawn Donovan, *Facilities Planning Office*

Abstract. A commuter fringe benefit program can be an effective vehicle for addressing the parking and traffic issues resulting from an institution's growth and development. But the most effective program can also be very expensive to implement and can create employee expectations that are difficult to reverse. For these reasons, it is important to use the best available methods to anticipate the optimal configuration of the program before it is implemented. This paper describes the method that was developed to evaluate and test commuter fringe benefit alternatives for Dartmouth College's 3,500-employee main campus.

Although Dartmouth College is located in a relatively rural setting in Hanover, New Hampshire, parking capacity is extremely limited currently and will become even more so as the College's current Master Plan proceeds. In addition, the road network in Hanover is approaching capacity and key links experience peak congestion. In 2001, Dartmouth's Facilities Planning Office began exploring commuter fringe benefit options as a way of complementing planned campus changes. Recognizing that the design of a cost-effective plan depended on an understanding of how employees would behave when offered those options, the College undertook a detailed survey of its employees to collect that information.

The Dartmouth Commuter Fringe Benefit Survey was designed as a web-based revealed and stated preference survey, asking both about current parking and travel behavior as well as likely behavior given different fringe benefit program designs. The survey was made available to all of the College's employees to ensure that none felt "left out" of the process. Almost all of Dartmouth's employees have web access and those who did not were given access to complete the survey. Over 1,500 respondents, representing 40% of all listed employees, completed the questionnaire during the two-week survey period in October 2001. In addition to completing the questionnaire, respondents provided over 150 pages of written comments supplementing their answers.

Data from the survey were used to construct a Commuter Fringe Benefit logit choice model, which estimates participation shares given parking fee levels, parking cash-out amounts, number of monthly passes provided to those who cash out and level of transit service provided. The model showed that relatively high participation rates could be achieved and that certain program configurations are highly cost-effective compared to the cost of constructing new parking and roadway capacity. The model also was used to estimate the effect of an initial pilot implementation of the program.

Introduction

In theory, a commuter fringe benefit program can provide positive returns to three key sets of stakeholders. Employers can benefit by saving money on parking and taxes and by

increasing employee satisfaction. Those employees who participate can benefit through reduced commuting costs. And, both employees who do not participate as well as the community at large may benefit from reduced traffic and congestion.¹

In practice, however, the program must be designed carefully to ensure that it delivers all of those returns. If the program is under-subscribed, the cost of administering the program may not be justified by the benefits. Similarly, if the program is over-subscribed, employer costs may exceed available budgets and result in both under-utilized facilities (e.g., parking) and over-capacity facilities (e.g., transit system).

Dartmouth College has over 3,200 employees at its Hanover, New Hampshire campus. Most employees drive to work and park in surface lots within and at the periphery of the campus. Dartmouth's parking permit system had fees ranging from \$54 to \$120 per year and free parking at peripheral lots served by a shuttle bus system, run by Advance Transit, which also operates a fixed route service to surrounding towns.

As part of a broader facilities master planning effort, Dartmouth evaluated a number of options to deal with existing and projected campus parking deficiencies and traffic congestion on the roads leading to the campus. The options for dealing with parking included structure lots are the only way of providing additional parking supply within the space-limited campus area.

Structured parking is much more expensive than the existing surface parking and it will not address traffic congestion issues. As a result, Dartmouth decided to evaluate commuter fringe benefit options to complement the parking and traffic elements of its master plan. This paper describes the analyses that were conducted to evaluate those options and the result of implementing a trial commuter fringe benefit program.

Approach

Several types of data were collected through Dartmouth's parking permit system that, together, provide information about the numbers and locations of cars parking on campus. However, these data alone were not sufficient to evaluate new alternatives that could be used to reduce on-campus parking demands. A stated preference survey was developed to collect more detailed data to support this evaluation.

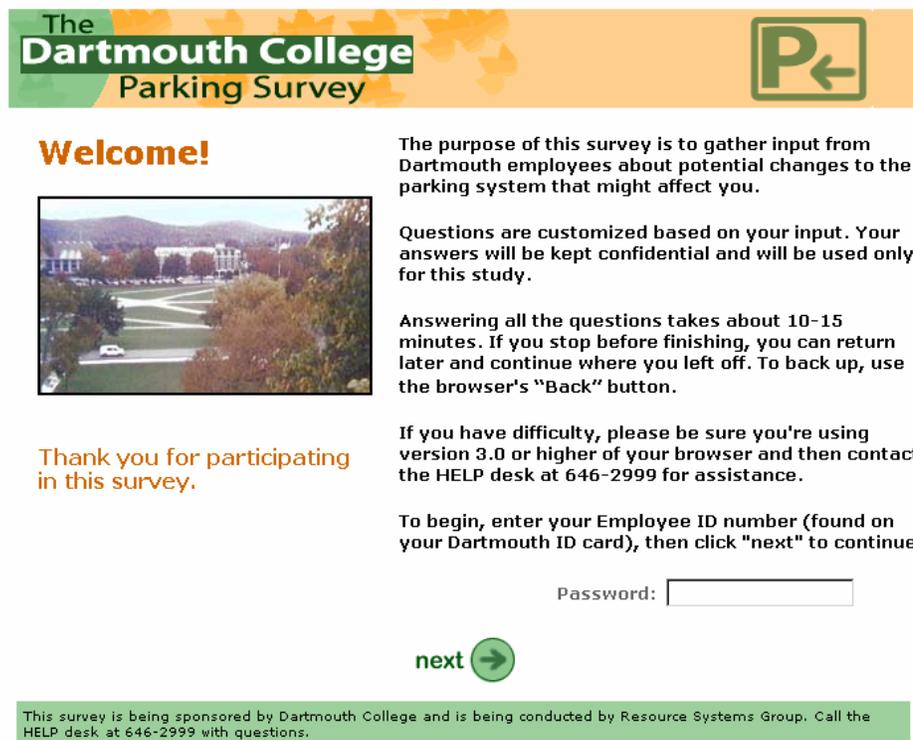
The survey questionnaire, which was designed with guidance and input from Dartmouth's Parking Steering Committee, was made available as a web-based instrument to all Dartmouth employees. Dartmouth, like most college campuses, provides Internet access and e-mail to most of its employees, making it an ideal application for a web-based survey. In departments where Internet access is more limited (e.g., facilities

¹ See, for example, ICF Consulting, et al, *Strategies for Increasing the Effectiveness of Commuter Benefits Programs*, TCRP Report 87, Transportation Research Board, Washington, D.C., 2003

maintenance), computers were set up and survey staff were made available to assist employees as they completed the survey.

The questionnaire collected information about employees' parking patterns, their perceptions of current conditions and their likely reactions (stated preferences) to new parking program alternatives. The survey instrument was developed using Resource Systems Group's IVIS system,¹ which is designed to support the wide range of computer operating systems and Internet browsers that were used on the campus. The survey was password-protected, ensuring that each employee completed the survey only once and allowing employees to complete the questionnaire over multiple browser sessions. The introductory survey screen is shown in Figure 1 below.

Figure 1-- Introductory Survey Screen



The questionnaire collected detailed information about employees' commuting patterns and, in particular, about characteristics that might prevent them from being able to participate in a commuter fringe benefit program. Those who might be eligible for the commuter fringe benefit program were given a set of stated preference scenarios in which

¹ Adler, T. and L. Rimmer, *Computer-Based Intelligent Travel Survey System*, US DOT/FHWA project report, September 2002.

different elements of the program were systematically varied according to an orthogonal fractional factorial plan.¹

Parking fees were varied at levels between 0.2 to 0.4% of salary, which were significantly higher than the existing rates. The commuter fringe benefit plans that were tested provided a \$30 to \$65/month cash payment, a range of free bus services and between 2 and 6 one-day parking passes per month. Employees were asked whether they would choose to register their car for the year or opt for the commuter fringe benefit program. An example stated preference scenario is shown in Figure 2 below.

Figure 2 -- Example Stated Preference Scenario

How would you get to work?

Option 1: REGISTER TO PARK	Option 2: REGISTER FOR VOLUNTARY COMMUTER FRINGE BENEFIT
Parking fee is \$21 per month	You get 2 parking passes per month Commuter fringe benefit is \$65 per month Free bus service includes shuttle service that circulates through your neighborhood every 30 minutes
<p>I would :</p> <p><input checked="" type="radio"/> continue to DRIVE</p>	<p>I would:</p> <p><input type="radio"/> get DROPPED OFF</p> <p><input type="radio"/> CARPOOL (in a carpool of 3 or more people)</p> <p><input type="radio"/> VANPOOL</p> <p><input type="radio"/> WALK</p> <p><input type="radio"/> BIKE</p> <p><input type="radio"/> take FREE BUS</p>

Information in **this color** changes for each situation

Situation **1** of **9**

An article about the survey was posted in the campus newspaper in advance of the survey period and employees were individually invited to participate through e-mail and a postcard mailing. Over 1,500 respondents, representing over 40% of all listed employees, completed the questionnaire during the two-week survey period. In addition to completing the questionnaire, respondents provided over 150 pages of written comments supplementing their answers.

¹ For a detailed description of stated preference survey and modeling methods, see: Louviere, J., D. Hensher and J. Swait, *Stated Choice Methods*, Cambridge University Press, © 2000.

Comparisons were made between the survey respondents and the full Dartmouth employee population. Figure 3 and Figure 4 below compare the survey respondents to known information about the employees who had registered for parking permits. These comparisons indicate that the sample matches the population reasonably well.

Figure 3 -- Employees' Commuting Route

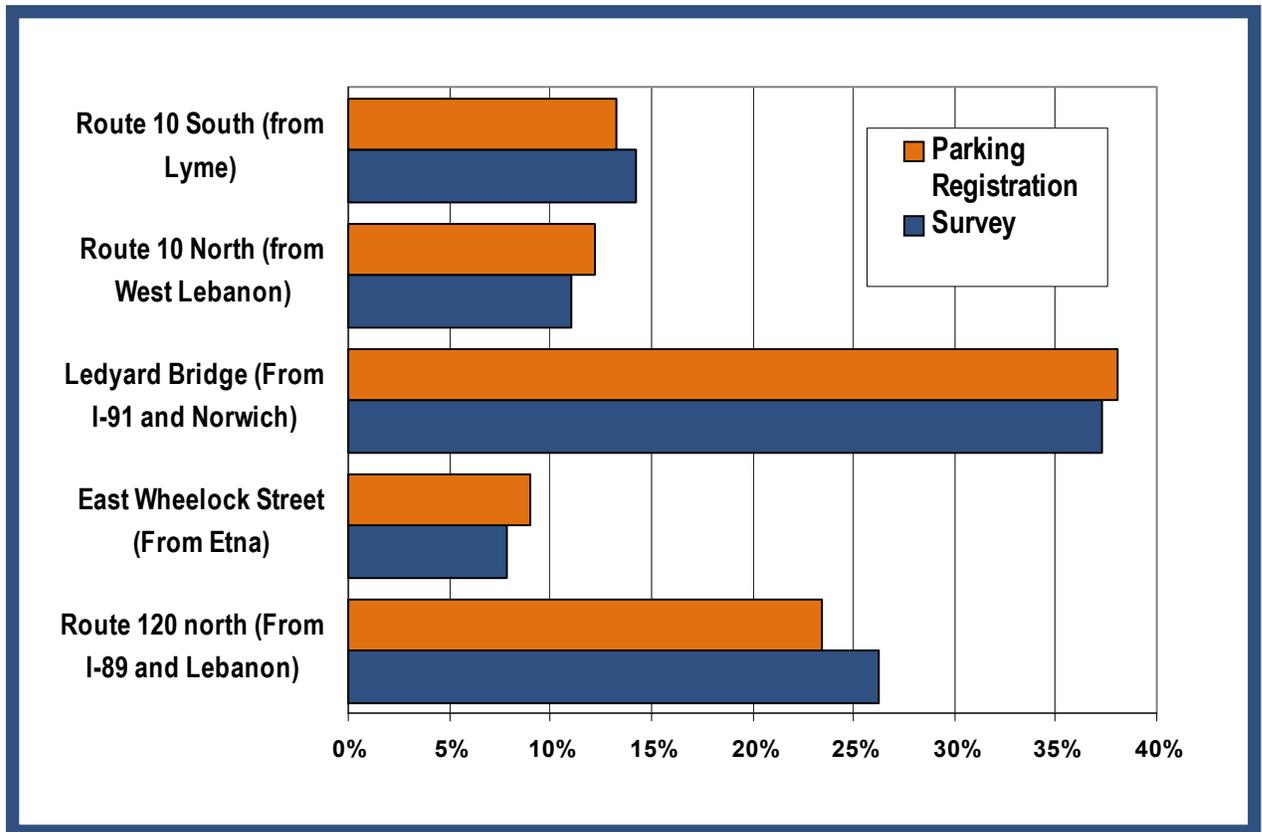
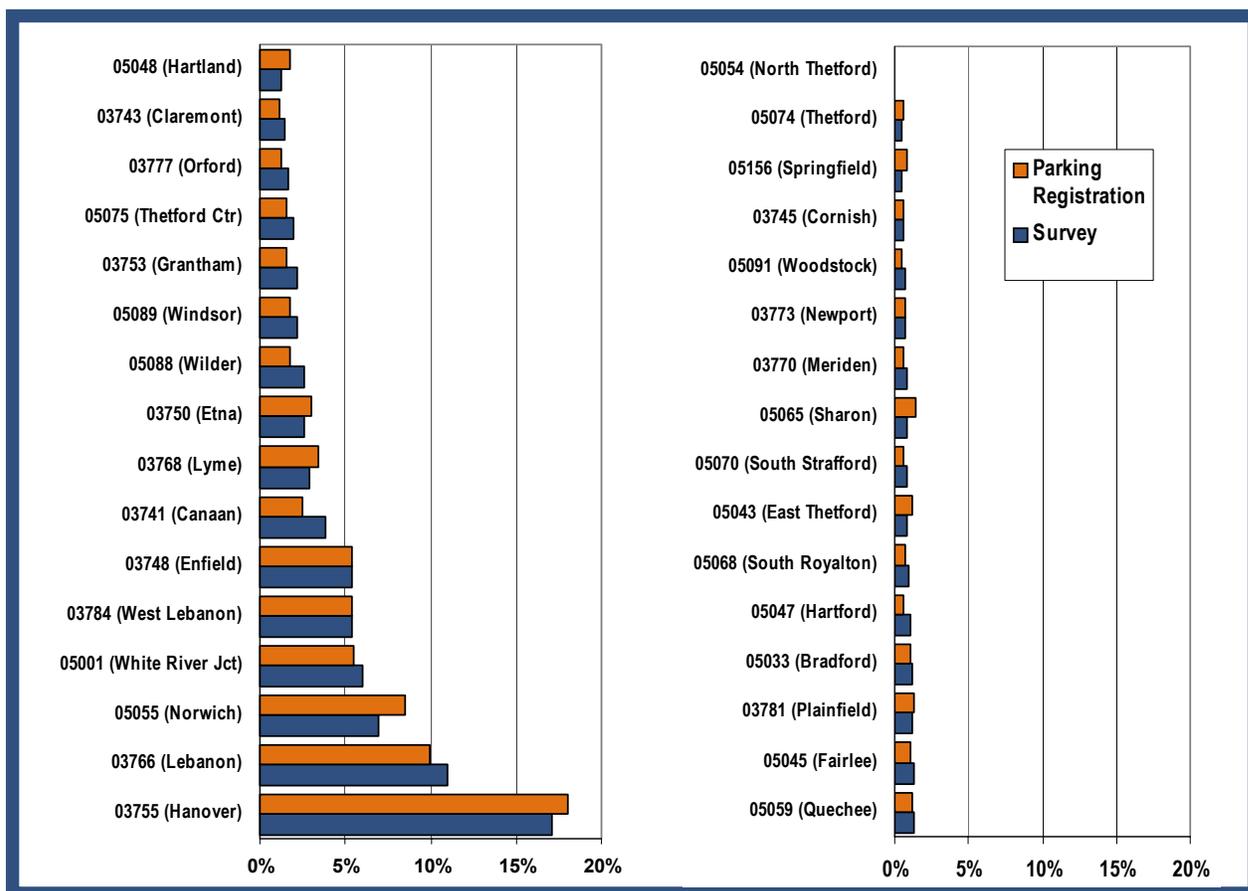


Figure 4 -- Employees' Residence Location



Current Parking Patterns

Of the 1,500 employees who responded, about 85% worked on campus, 5% worked in other downtown Hanover locations and the remaining 10% worked at a location outside Hanover. Of those who worked on campus, 8% did not currently register to park their vehicle on a campus lot, most because they currently walked, biked or carpooled to work. As is typical in all but the largest U.S. metropolitan areas, the vast majority of Dartmouth employees commute to work by car:

- Over 75% of employees usually drove alone to work,
- 14% drove with others in the car (including their children),
- 5% walked or biked, 3% got dropped off by others,
- 2% rode the bus and 1% carpooled.

Hourly (non-exempt) employees had the highest drive alone shares (78%) and faculty had the lowest (71%). This was in part because a higher percent of faculty live in Hanover within walking and bicycling distance to campus.

The traffic created by employees' trips to work is concentrated along certain access routes and within typical commuter peak hours. To get to work:

- Over 37% accessed from the west (across the 2-lane Ledyard Bridge),
- 26% drove in from the southeast along Rt. 120,
- 14% drove along Rt. 10 from the north,
- 11% came from Rt. 10 south and
- 8% accessed from the east (Wheelock St.)

Of these routes, the two routes that account for almost two-thirds of the total Dartmouth employee traffic (Ledyard Bridge and Rt. 120) experience moderate to heavy congestion during peak periods. Approximately 80% arrived at work during these peak periods between 7 AM and 9 AM and left work between 4PM and 7 PM. Employees are currently affected by both limited parking supply and roadway congestion: over 25% of employees said that they chose their work hours in part to allow them to get a parking spot on campus and over 20% chose their hours to avoid the worst traffic congestion.

The median commuting time was about 25 minutes; this is slightly longer than the national average commute of 20 minutes. Faculty have the shortest commutes at about 20 minutes with hourly employee commutes averaging closer to 35 minutes.

Perceptions of the Current System

Approximately 23% of all employees who used a car to get to work thought that it was possible for them to use a bus to get to work, given the existing Advance Transit routes. Adding park-and-ride lots, adding express service, extending the service area and extending service times were cited as inducements for using the bus to those employees. For those who used a car but did not carpool:

- 60% indicated that they could not carpool because of schedule changes or because of stops made to or from work (respondents could select multiple reasons)
- About 40% needed their car during the day and
- 33% simply did not know others who are willing to carpool.
- Ratings of the existing parking system were mixed.
- Almost 70% of employees rated the location and safety of their parking as either good or excellent,
- Only 38% rated the availability of parking as either good or excellent,
- Over 50% of employees rated availability on the lowest two points of the five-point scale,
- 25% rated availability at the lowest level (poor),
- Current parking prices were rated with almost equal frequency across the five-point scale (poor, fair, neutral, good excellent).
- The overall parking experience had a similarly mixed rating.

Commuter Fringe Benefit Choice Model

As described earlier, employees who used their car to get to work were asked to respond to a series of stated preference scenarios to determine what combination of incentives, if any, would cause them to choose an alternative commuting mode. The data from these questions were used to develop a binary logit parking choice model that, in turn, was used to estimate the number who could be expected to enroll in the commuter fringe benefit program and switch to these alternative modes.

The binary logit model is structured with enrollment in the commuter fringe benefit program as the base condition and enrollment in the regular parking permit program as the alternative. Coefficients of the statistically estimated model are shown in Table 1 below.

Table 1-- Binary Logit Commuter Fringe Benefit Choice Model Coefficients

Model Variable	Coefficient	T-Stat
Parking Permit Fee (0.1% of salary)	0.3575	15.6
Daily Passes (number/month)	0.08328	7.3
Cash Benefit (\$/month)	0.009133	7.1
Bus Headway (minutes)	-0.01226	-8.2
Express Bus (0,1)	0.01944	0.4
Commuter Benefit Constant	-2.123	-18.3

The models indicate relatively strong sensitivity to permit fees all of the program variables, but with a large negative base constant reflecting those who would not use the commuter fringe benefit program under any circumstance. Employees' reactions to the commuter fringe benefit options indicate that a significant fraction would participate if the program provided reasonable cash payments, a good bus transit alternative and some flexibility to park on campus for a limited number of days each month. The commuter fringe benefit program could be structured to accomplish a wide range of on-campus parking reductions. Five program designs were developed to illustrate the range of costs and parking impacts that would result from different program configurations.

Evaluation of Program Options

A simple spreadsheet model was developed, using the logit model to estimate program enrollments and using data on the existing parking permit program. The spreadsheet model was used to evaluate the five example fringe benefit program designs. Table 2 below shows the results of these analyses.

Table 2 -- Evaluation of Commuter Fringe Benefit (CFB) Program Options

Parking Scenario Description	Net Reduction		Incremental Net Costs (\$/yr)	Net Cost/Space Reduced (\$/yr)	CFB share	# Forgo Pkng	
	in Spaces	CFB Cost (\$/yr)				Permit	# Pkng permits
A Base CFB, New Buses, 0.2% Fee	320	200,000	530,000	1,700	0.15	360	2,040
B CFB w/ 4 passes, New Buses, 0.3% Fee	450	270,000	530,000	1,200	0.23	560	1,840
C Base CFB, No New Buses, 0.15% Fee	140	130,000	170,000	1,200	0.07	160	2,240
D Aggressive CFB, New Buses, 0.3% Fee	640	540,000	1,130,000	1,800	0.33	800	1,600
E Base CFB, New Buses, 0.4% Fee	580	300,000	510,000	900	0.27	640	1,760

The percent of employees enrolling in the commuter fringe benefit program ranges from 7% under program C, with a \$30/month benefit and no new bus service (but free fares on the existing buses) to 33% under the most aggressive program with new bus service and a \$45/month cash benefit (program D). The program costs estimated in the table include the program cash disbursements plus the possible cost of providing new bus service and operating peripheral park-and-ride lots.

The incremental net cost includes the reduction in parking fees collected. The net cost per parking permit relinquished in the program ranges from \$900 to \$1,700 per year. The net costs for the more cost-effective designs compare favorably to the costs of new structured parking spaces at \$1,500 per year. In addition, the reduction in on-campus parking induced by the program in turn reduces traffic on the access routes to the campus.

Parking Program Recommendations

All of the scenarios result in a significant reduction in on-campus parking. Reductions of over 600 spaces are possible with the most aggressive implementation, but at a higher net cost per space. The less aggressive options are somewhat more cost-effective. The lowest cost option is to simply offer a commuter fringe benefit option without adding any substantial new bus service. The intermediate options provide a range of displaced parking amounts, at net costs that are intermediate between the two extremes.

Two of the program design variables that have significant effects on program enrollment are provision of new bus service and parking fee levels. New bus service is defined here as including neighborhood shuttle service in Hanover with express buses from park-and-ride lots for all of the other major access routes. Most employees who were receptive to the commuter fringe benefit indicated that this service would be much preferred over carpooling and other options. As a result, the model shows significant enrollment gains when this service is offered. The cost of providing the bus service is considerable and the increased enrollment it causes also increases the total commuter fringe benefit payout costs.

Parking fee changes also affect overall program effectiveness and costs. Increasing parking fees will cause a significant increase in commuter fringe benefit enrollment. The additional enrollment costs are only partly offset by the higher revenues from those who

continue to buy parking permits. These results can be used as a guide to formulating an “optimal” parking program that meets current and future parking needs. However, three specific considerations suggested that the initial implementation should be more modest and treated as a “trial”:

- The costs of the program are considerable,
- There was some uncertainty as to how well the stated preference model would predict actual behavior and
- There was significant sensitivity to changes in employee benefits.
- As a result, a trial program was recommended for the 2002/2003 academic year.

Results of the Commuter Fringe Benefit Trial Program

The 2002/2003 Dartmouth commuter fringe benefit trial program offered a \$30 cash benefit to all employees who had purchased a parking permit in the previous year, in return for forgoing a parking permit in the current year. Bus service on all existing routes was offered fare-free for all Dartmouth employees. The program design is most similar to design C in Table 2. Program enrollments are approximately 175 – very close to the 160 estimated for design C.

As campus development proceeds, the program will likely be expanded to both meet parking program needs and to offset traffic impacts of the new development. Increasing parking permit fees and establishing new bus service will be the most effective approaches for increasing enrollments. The costs to Dartmouth of new bus service will be reduced if the service is developed jointly with other major regional employers.

Conclusions

Commuter fringe benefit programs can provide cost-effective ways to reduce demand for parking. However, for large employers, it is especially important for the costs and benefits from these programs to be estimated in advance of their implementation. The survey and modeling approach that was developed to support Dartmouth College’s evaluation of commuter fringe benefit options provided detailed information about the likely enrollments in a wide range of possible plans. The models showed that there would be positive net benefits under most plans, compared to the costs of building new structured parking and not accounting for the benefits from reduced traffic congestion. The models indicate that the Dartmouth program could reduce the need for major increases in the parking inventory.

The commuter fringe benefit program implemented for 2002/2003 resulted in enrollments very close to the levels predicted by the model: 160 estimated by the model vs. 175 actual. This experience suggests that a logit-form commuter fringe benefit choice model estimated using stated preference survey data provides a reasonable tool for use by large employers in evaluating these programs.

Assessing Sampling Biases and Establishing Standardized Procedures for Weighting and Expansion of Data

Fahmida Nilufar, *Louisiana State University*

Abstract. Recent household travel surveys are encountering problems with non-response, non-coverage, non-reporting, and even incorrect or incomplete reporting of trips. Moreover, the procedures used to conduct, design, and implement the surveys can introduce error into the data. However, these threats to the integrity of the data are often ignored while analyzing sampled survey data. As a result, the potential for bias in household travel surveys has become a matter of concern.

This study documents an in-depth investigation into the state of practice of recent household travel surveys on issues of survey bias, survey error, and overall survey quality. This has been accomplished by reviewing a few recent household travel surveys in depth. The review has focused on the presence and extent of bias observed in those surveys, appraising the instruments and the methods of data collection used, and finally, observing the methods used for correction of biased data.

The quality of past surveys will be assessed by comparing the values (mean and proportion) of selected survey variables with those from some standard secondary data source (census, PUMS), as well as, by considering their variability (sampling) error. The study demonstrates the application of weighting and factoring (expansion) techniques on sampled data by applying the most appropriate weighting and factoring techniques on a selected set of sampled data at the household, person, and trip levels.

Introduction

Household travel data is collected to obtain information on the amount and nature of personal travel in a region. In addition to providing information on travel made by the people of a region, these data are utilized in a number of ways. It allows analyses of trends in travel patterns and identifies areas where problems are expected (Stopher, 1995). Additionally, it provides input for travel forecasting and other models, which are used to identify long-range transportation problems, as well as to update travel demand models. Furthermore, in recent years, an increased demand for a better transportation planning process arising from environmental and congestion concerns has created a need for more sophisticated modeling in transportation planning. The need for increasingly complex modeling has increased the demands on model inputs, specifically, travel survey data (Zmud, and Arce, 1997).

The household travel data are typically generated through a household based survey in which demographic information and travel patterns of a sample of population are recorded for a given period of time. From the information provided by the respondents in such

surveys, a relationship is developed between the household demographics, it's individuals and their travel pattern.

Considering the importance of travel data in transportation planning of a region millions of dollars are spent by the metropolitan planning organization to collect information on travel. However, for data to be useful to transportation planners, a survey must furnish accurate information on travel.

Household travel surveys have always been a problem for many reasons. Literature on household travel surveys suggests that some persistent problems exist in the conduct, design, and implementation of travel surveys. For example, recent household travel surveys have experienced a drop in response rate (Stopher, 1995). Surveys also often contain incomplete and incorrect data, or use a sampling frame that routinely ignores certain segments of the population, sometimes an instrument is used that prevents respondents from giving the correct answers to survey questionnaires. These conditions introduce bias into the sampled survey data.

While transportation planners have employed personal travel surveys for over 40 years, lack of standards in the design, implementation, and analysis of survey data has limited transportation planners from achieving an acceptable level of quality and reliability in sampled surveys. These shortcomings in the quality of data have often been ignored when analyzing the survey data. Therefore, for the proper and effective use of travel survey data generated through household based surveys, analysis of data for the presence of bias is required.

Hence, this paper is aimed at developing measures, which treat biased data. To accomplish this, the study has reviewed the measures used in past surveys to correct the biased data. A few recent household travel surveys have been reviewed for this purpose to,

- Identify the variables used in those surveys to assess bias
- Identify circumstances that typically lead to the need for weighting and expansion of survey data (e.g., households with multiple telephone lines, households that shared telephone with others, non-responding households, etc.), and developing equations for each identifying circumstance.

A weighting and factoring process is subsequently applied to a household travel survey data to demonstrate the procedure.

Review of Past Survey Practices

A few recent household travel survey reports have been reviewed as a part of this study. The study includes the following surveys:

- The 1997-98 Regional (New Jersey, New York, Connecticut) Travel Household Interview Survey
- The 1995 Origin Destination Survey for Northwestern Indiana
- The 1996-97 Corpus Christi Study Area Travel Survey
- The 1996 Bay Area Survey

- The 2000 Southeast Florida Regional Travel Characteristics Survey
- The 1991 California Statewide Survey
- The 1998-99 Greenville Travel Study
- The 1993 Wasatch Home Interview Travel Survey
- The 1996 Broward Travel Characteristics Survey.

Identified Variables

Five of the above nine surveys reported identifying bias in their sampled data. Bias was determined from comparison of certain demographic variables of households and persons to their population counterparts in the Census' Public Use Microdata Samples (PUMS). Most of the surveys used similar socio-demographic characteristics of the household and person data to identify bias.

In the household data, the usual variables are household size, household vehicle availability, number of household workers, household home ownership, and household income. In the person data, age, gender, employment status, and drivers license status were often used.

Three key conditions in households were identified where bias was often observed. They are:

- Households with 4 or more persons (under-represented),
- Households with no vehicles (under-represented),
- Households earning less than \$10,000(under-represented).

The extent of bias observed in those surveys is illustrated in Table 1. The other variables that were under-represented are, household having no-workers, and those with more than 2-workers. Additionally, the observations of the person file depicts that persons in the age groups 19 – 35 are mostly under-represented.

Table 1. Extent of Bias Observed in Past Surveys

Survey	Biases Identified
➤ The 1997-98 Regional (New York, North Jersey) Travel Household Interview Survey (RT-HIS)	<u>Household variables</u> <ul style="list-style-type: none"> ▪ Households with 4 or more persons (5.1 % under-represented), ▪ Households with no vehicles (9.1% under-represented), ▪ Households earning less than \$10,000 (7.1% under - represented)
➤ The 1996 Bay Area Travel Survey	<u>Household variables</u> <ul style="list-style-type: none"> ▪ Households with 4 or more persons (8.4% under- represented), ▪ Households with no-vehicles (4.6% under- represented), ▪ Households earning less than \$ 10,000 (5.6% under-represented), ▪ Households with no workers or more than two workers (3.5% % under-represented) <u>Person Variables</u> <ul style="list-style-type: none"> ▪ Age 19 – 29 years of old (5.6% under-represented) ▪ Unemployed (1.6% under-represented)
➤ The 1996 Broward Travel Characteristics Survey	<u>Household Variable</u> <ul style="list-style-type: none"> ▪ 4+ person households (12 % approx. under-represented) ▪ No- vehicles households (8% approx. under-represented) ▪ Non-employed household (28 %over-represented), ▪ Single family units (over-represented),
➤ The 1995 Origin Destination Survey For Northwestern Indiana	<u>Household Variable</u> <ul style="list-style-type: none"> ▪ Small size household (over-represented) <u>Person Variable</u> <ul style="list-style-type: none"> ▪ Older people (over-represented)

Identified Circumstances

Circumstances responsible for introducing bias in the sample data during data acquisition processes were identified from the information provided in past surveys.

Factors such as, disproportional sampling rate, non-homogenous telephone distribution pattern, unequal selection probability of sample due to multiple, or shared telephone lines in households, households with missing records, as well as, bias induced by differential response rates, non-response, non-coverage were identified and considered in the data adjustment process.

Data weighting is suggested when a stratified sampling procedure is used with disproportionate sampling rate. For example, a particular study may require over sampling of one or more subgroups of a population, or one or more counties in a region in order to get design samples for a specific analysis. In such cases, weighting is required to adjust the sampling rate for any activity that will combine data from different strata of the sample. Furthermore, weighting compensates the unequal probabilities of selection of individual

cases as well. Differences in the sample selection process often occur due to the sampling strategies adopted in surveys. For example, in a telephone survey households with multiple telephone lines have more chances of being selected in the sample than households with a single line.

Weighting also accounts for the differences in response rates between subgroups. No matter how representative the sample is of the larger population, differences in response rates between subgroups can introduce systematic discrepancies between the sample and the population. Weighting adjustment can reduce such bias.

Weighting adjustments are also suggested to adjust the survey data for known discrepancies between the survey sample and the population values. For example, if one area is over represented in the survey sample purely by chance, census data can be used to adjust this departure from the population distribution. In addition, adjusting the data to known population totals can help reduce the impact of non-coverage, non-response etc.

The weighting factors that were developed to compensate for each biasing circumstance are discussed below.

Weighting and Expansion of Data

Weighting for Unequal Probability of Selection

- **Disproportionate Stratified Sampling.** In a stratified sample design, the populations first divided into subgroups called “strata” and separate samples are selected within each stratum. Different sampling probabilities are often used within the different strata. To derive any population statistic from the sampled data, it is required to combine data from different stratum of the sample. When the sampling rates are not proportionate to the stratum population, the base weight must be adjusted to account for the differences in the sampling rate in each stratum as follows:

$$W_{1h} = w \times a_h = w \times \frac{N_h / N}{n_h / n} \quad w \dots\dots\dots (1)$$

where,

W_{1h} = adjusted household weight for stratum h.

w = base weight for each sampling unit in the sample = $\frac{1}{n / N}$

a_h = adjusted weight in stratum h = $\frac{N_h / N}{n_h / n}$

N_h = population in stratum h, and $N = \sum_1^H N_h$

n_h = sample size in stratum h, where, $n = \sum_1^H n_h$

- Multiple Telephone Households. This weighting factor is required to adjust the base weight (w) to compensate for the fact that a household with multiple telephone lines has more than one chance of being selected in the sample. The adjustment factor is given by,

$$W_2 = w \times \frac{1}{t_m} \dots\dots\dots (2)$$

t_m = number of telephone lines in a household, and

W_2 = adjusted weight for multiplicity of telephone lines.

- Shared Telephone Households. This is introduced for those multiple households who share the same phone number. This weighting factor adjusts the data so that each telephone number represents one household.

$$W_3 = w \times t_{mst} \dots\dots\dots (3)$$

where, t_{mst} = number of households that share one line

- Episodic Telephone Services Households. It has been established in past research that telephone ownership is a variable condition for many U.S. households who lose and gain telephone status over the year. Episodic telephone ownership characterizes those households that have telephones when they can afford them, and the service is turned off when times get tough or when bills get too large. The problem with keeping such households in the interview process is that it requires too many telephone calls over time to complete the interview. These calls include the recruitment call, the household and person interview, the reminder call, and the data collection call. Some researchers suggest that if a sufficient quantity of these households are kept in the process and surveyed then the data may be used as a proxy to adjust the probability weights to account for the households not covered by telephone (NPTS, 1995) in RDD surveys. Therefore, an adjustment weight (W_4) in the base weight is suggested to account for the non-telephone and episodic telephone households.
- Normalization of Weights. This is required when the weighted data (weighting factor 1 through 4), under-represents or over-represents the actual sampled data. To accommodate the discrepancy this factor is developed as:

$$W_5 = w \times \frac{W_{sampled}}{W_{weighted}} \dots\dots\dots (4)$$

Weighting for Non-Response

The response rate (R_r) for survey units is calculated as the ratio between the actual number of sampled households (n) i.e., responding and non-responding households to the number of responding households (n_{res}) and is illustrated by:

$$R_r = \frac{\sum_1^{n_{res}} n_{res}}{\sum_1^n n} \text{ and the weighting factor, } W_r = \frac{1}{R_r} \dots\dots\dots(5)$$

Post-Stratification Weights

Post-stratification weights are aimed at adjusting the sample data for non-response, non-coverage, missing records and others discrepancies in the sample, as well as to expand the sample to population values. According to the expansion assumption, the sum of the weights for all sampling units (households) must represent an estimate of the size of the survey population. If independent estimates of the size of the population for each stratum of population in the sample are available, the sample can be post-stratified to bring the survey weights into agreement with outside population figures. Post stratification involves comparing the sum of the weights for a given subgroup with the population estimate for that group. The post stratification adjustment is calculated by multiplying the adjusted weight of cases in a sub-group, say subgroup j, by the ratio between the population estimate for that sub-group (say, N_j) and the sum of the weights for sample cases in that sub-group as:

$$w_p = w_{j\text{adjusted}} \frac{N_j}{\sum w_{j\text{adjusted}}} \dots\dots\dots(6)$$

where, w_p is the post-stratified adjusted weight, $w_{j\text{adjusted}}$ is the adjusted weight of cases in subgroup j, and $\sum w_{j\text{adjusted}}$ is sum of their weights for sample cases in that subgroup before any population correction is applied, and N_j the population estimate for that subgroup.

Demonstration of Weighting and Expansion Procedures

The ‘Phoenix Household Travel Survey of 2000’ was selected for analysis to demonstrate the application of weighting and expansion process on sampled data. Information on households with multiple telephone lines, households having shared telephone lines, households with missing records, differential response rates, non-response, non-coverage etc was available in the data. The data weighting was carried out at three levels:

- The household level
- The person level
- The trip level

Household Weights

The development of a household weight for the Phoenix data is achieved in two steps. In the first step, sampled data is weighted for multiple telephone ownership, shared telephone lines, and non-telephone households. Weighting is subsequently applied to account for the missing records in the household observations. Multiplying each data value by the appropriate weight and summing the results lead to the final weighted totals for the step 1 of the weighting process. A normalized weighting factor is developed to bring the weighted samples to actual sampled data.

The second step in the data weighting process is aimed at adjusting the weighted data from step 1 so that they agree with the population counts provided by the Census. The adjustment is an iterative weighting and expansion process, which adjusts the expanded sample iteratively to match the census household estimates on several household demographics.

The Initial or Base Weight

The number of sampled households in the Phoenix household travel survey is 4018. According to Census 2000, there are a total of 1,132,886 households in Maricopa County, Arizona. Therefore, the probability of selection Pr_i of each surveyed households is:

$$w = \frac{1}{Pr_i} = \frac{1}{\frac{4018}{1,132,886}} = 281.95$$

Weighting For Differences In Selection Probability

The household level weight factor for the Phoenix households is comprised of elements that aim to adjust the survey data to correct for unequal probability of selection, for telephone ownership patterns and for the non-telephone households of the study area. It is observed that no household in the Phoenix survey data has the record of sharing a telephone with another household, therefore, the weighting excludes shared telephone lines from the weighting calculation.

Multiple Telephone Households

A number of the sampled households indicated that they have more than one working phone line that was not dedicated to fax or modem use. The weighting factor to account for multiple telephone lines per households is developed through a two-step process. First, the actual number of voice lines available to each household was determined by subtracting the number of fax lines from the total number of phone lines available to the household. Then, a factor was created to adjust the data to compensate for cases where more than one phone line is available. The conditions in the Phoenix data are shown in Table 2.

Table 2: Number of Telephones lines for households in the Phoenix Survey

#tel.lines–# faxlines	# of Households	# of telephone lines presented
0	10	0
1	3646	3646
2	287	574
3	47	141
4	7	28
5+	6	33
*DK/RF/missing	15	-
Total	4018	4422

*DK/RF= Do not know/ Refused

It is observed from Table 2 that a total of 4422 telephone lines are available to 4003 households (excluding the DK/RF records). The probability of selection of each one-telephone household of the study area is,

$$\Pr_{t1} = \frac{4003}{4422} = 0.905, \quad \text{and the weighting factor, } w_{t1} = \frac{1}{\Pr_{t1}} = 1.105$$

The multiple telephone households require a weighting factor to adjust for multiplicity as given by:

$$w_m = \frac{1}{\Pr_{t1}} \times \frac{1}{t_m} = w_{t1} \times \frac{1}{t_m},$$

w_{t1} = weighting factor that account for equal selection probability for each household

w_m = the weighting factor to adjust for multiple telephone lines

t_m = number of telephone lines available to each household

Applying the weighting adjustments for multiple telephone lines,

$$w_m [3646 \times w_{t1}/1 + 287 \times w_{t1}/2 + 47 \times w_{t1}/3 + 7 \times w_{t1}/4 + 6 \times w_{t1}/5] = 4422$$

$$w_m [4208] = 4422, \quad w_m = 1.051$$

and, for the 15 missing data on telephone ownership:

$$w_{t \text{ missing}} = 1 / \frac{4003}{4003 + 15} = \frac{4003}{4018} = \frac{1}{0.996} = 1.004$$

Therefore, the final weighting factor for multiple telephone households (Table 3) is:

$$w_{mult} = w_{t1} \times w_m \times w_{t \text{ missing}}$$

Table 3: Factors for multiple telephone households in Phoenix survey

Number of phone lines/household	Weighting factors (w_m)	Final Weights w_{mult} ($w_m \times w_{t\text{ missing}}$)
1	1.051	1.055
2	0.525	0.527
3	0.350	0.351
4	0.263	0.264
5+	0.21	0.21

Non-Telephone households

Data weighting is applied to account for non-telephone households in the study area by considering the data reported by households that have disrupted telephone services for a period of more than two weeks (episodic telephone service). In fact, these households represent a part of the non-telephone households of the study area.

Of the total 4018 households surveyed in the Phoenix survey, 3773 (93.9%) households reported non-disrupted telephone services to their households during the previous twelve-months [Table 4]. Among the remaining households, 192 households (4.8%) reported service interruption in their households during the past twelve months.

Table 4: Non -Disrupted and disrupted telephone ownership in the Phoenix survey

Lack of Phone Service	Frequency	Percent
Non- disrupted	3773	93.9
Disrupted	192	4.78
Do not Know	50	1.24
Refused	3	.08
Total	4018	100

The 192 households that reported service interruptions in their households were again classified according to the length of time they were without telephone service as non-episodic (less than two weeks) and episodic (more than two weeks) telephone service ownership (Table 5). Therefore, depending on length of service interruptions, an additional 102 (service interruption less than two weeks) households from the 192 interrupted telephone households were added to the original 3773 no- service interrupted households adding up to a total of 3875 (96.4%) households as non-episodic in the study area.

Table 5: Episodic Telephone Ownership as reported in the Phoenix survey

Length of time without telephone service	Frequency	Percent
No service interruptions (non-episodic)	3773	93.9
Less than 2 weeks (non-episodic)	102	2.5
2 weeks but less than 1 month	24	0.6
One month but less than 3 months	23	0.6
Three months to less than six months	17	0.4
Six months or more	20	0.5
Do not Know	5	0.1
Refused	1	0

A total of 59 households fell in ‘Do not know’ and ‘Refused’ categories (Table 4 and 5), which occurred during the data collection phase that determined the episodic, and non-episodic telephone ownership status of surveyed households. Among the 59 households, 53 households did not provide information on ‘disrupted’ and ‘non disrupted’ telephone services to their households (Table 4), and an additional 6 households (Table 5) did not provide information on the next question, i.e., length of time the households were without telephone services. These households were considered as missing record households in the adjustment process.

To account for the missing records in the telephone ownership status, and the episodic telephone services, three weighting factors are developed. First, an adjustment (w_{ep1}) to account for missing records in interrupted telephone ownership, and a second adjustment (w_{ep2}) to account for missing records in episodic ownership status and the final factor (w_{ep}), which is the product of the two factors.

$$w_{ep1} = \frac{1}{\frac{3965}{3965 + 53}} = \frac{1}{\frac{3965}{4018}} = 1.0133, \quad w_{ep2} = \frac{1}{\frac{3959}{3959 + 6}} = \frac{1}{\frac{3959}{3965}} = 1.0015$$

$$w_{ep} = 1.0015 \times 1.0133 = 1.015$$

The weighted data shows that 3933(97.88%) households of the study are non-episodic and 85 (2.12%) households have the records of episodic telephone services. However, according to census estimate of 2000, about 2.07% households of the study area are non-telephone households.

Although, the census contains information on total non-telephone households of the study area, direct comparison of the two sets of data to develop the weighting factor was not feasible because of lack of information in the census about those households experiencing

an episodic telephone service at the time of census. However, using the sampled data, an analysis was made to get an approximate figure of the percentage of households in the study area that could be episodic. From a statistical analysis of the episodic telephone households of the study area, it is estimated that the surveyed households were out of service for an average period of 11 weeks (approx. 3-months). If these surveyed households represent the true population conditions on interrupted telephone services, then there is a probability that the census observations of total non-telephone households include approximate 25% percents of the episodic telephone households. Thus, this analysis result was used to predict the census percentage of permanently non-telephone households of the study area and the episodic telephone services households.

$$\% \text{ Households in the census with episodic telephone services} = 2.07/4 = 0.52\%$$

$$\begin{aligned} \% \text{ Households in the census permanently without telephone services} &= 2.07 - 0.52 \\ &= 1.55\% \end{aligned}$$

$$\% \text{ of telephone and permanently non-telephone households} = 100 - 0.52 = 99.48\%$$

Therefore, the weighting factor to account for permanently non-telephone household is,

$$w_{telhouseholds} = \frac{99.48}{97.88} = 1.016, \text{ and episodic telephone household, } w_{episodic} = \frac{0.52}{2.12} = 0.25$$

Therefore, the final adjustment factor to account for non-telephone and episodic telephone households is given by w_{fnon} and w_{fep} .

$$w_{fnon} = 1.015 \times 1.016, \text{ for households with regular telephone services, and}$$

$$w_{fep} = 1.015 \times 0.25, \text{ for households with disrupted telephone services.}$$

Weighting for Non-Response

Due to lack of information on response rate at different phases of data collection, it was not feasible to weight the data for non-responses resulting from non-responding households of the target sample.

Final Household Weight

Once each case (household) received a value for each of the weighting factors described above, the final household weight for step 1 weighting process is calculated through the multiplication of the factors as:

$$w_{h \text{ final}} = w_{multi} \times w_{fnon} / w_{fep}$$

It is observed that the weighted data at this stage when aggregated equals 4021 households in place of 4018 households actually sampled.

Normalized Household Weight: A normalized weighting factor is developed to bring the weighted samples to actual sampled data and is given by:

$$w_{h \text{ normalized}} = \frac{w_{\text{sampled}}}{w_{\text{weighted}}} = \frac{4018}{4021} = 0.999 = 1.00$$

therefore,

$$w_{h \text{ final normalized}} = w_{\text{mult}} \times w_{f \text{ non}} / w_{f \text{ ep}} \times w_{h \text{ normalized}}$$

Post- Stratification of Household Weights

The weighted data is finally post stratified to adjust for non-response, non-coverage, missing records, and to reduce the non-response bias from the sampled data. The basic concept is to adjust the sampling weights of the survey respondents so that they sum to known totals. The post-stratification adjustment alters the survey samples so that they agree with the population counts provided by the census.

For the purpose of post-stratification, the sampled households were classified into different demographic groups based on the information provided by the households during the survey. A 4-way cross-classified table (Table 6) with household size, household vehicle ownership, households' owner/renter status, and household income in various categories is prepared and presented. The survey samples in 160 classes in the 4-variable categories, the household size (1-person, 2-person, 3-person, 4+ person), household vehicles (0-veh, 1-veh, 2-veh, 3+ veh), household owner/renter status, and household income (< \$10k, \$10k-\$19.999k, \$20k- \$34.999k, \$35k-\$49.999k, and > \$50k) are presented (Table 6 -attachment).

Post- stratification involved comparing the sum of the weights for a given group with the population estimate for that group. Since, independent estimates of the size of the population in each subgroup cell (cross-classified cells) are not available, the sample is calibrated on margin to bring the survey weights into agreement with the outside population figures. An 'Iterative Proportional Fitting' procedure is used to calibrate on margin. This method is utilized to adjust the households weight simultaneously so the sums agree closely with the following marginal controls as provided by the census.

- Equal weight totals for each of the five income categories (\$<10k, \$10k- k19.999, \$20k- \$34.999k, \$35k- \$49.999k, and \$50k+
- Equal weight total for each of the four household size (1-person, 2-person, 3-person and 4+ person)
- Equal weight total for vehicle ownership categories (0-veh, 1-veh, 2-veh, 3+ veh)
- Equal weight total for house ownership status (owner, renter status)

In doing so, the basic expansion of sampled households to population households was first made. Thereafter, the process works by adjusting the weights to bring the survey figures into line with one set of population figures. Then they were adjusted to agree with the second set of population figures, and so on. This process is continued until the survey weights converge with four sets of population figures as given in the census.

If $n_{ihvo/r}$ represent the sum of the weights for the sampled data for a given cell in the four dimensional matrices representing income, household size, vehicles, and the owner/renter status.

Then, n_{i+++} the sums across the cells along income and n_{+h++} the total across the cells along the household size, n_{++v+} , and $n_{+++o/r}$ are sums along vehicle ownership, and owner/renter status of households, and N_{i+++} , N_{+h+++} , N_{++v+} , and $N_{+++o/r}$ represents the corresponding population figures.

Let w_o represent the initial weight of any cell before any adjustments are made to population figures. The new adjusted weight for the four population control conditions can be estimated as:

$$w_{ihvo/r}^{1,income} = w_{ihvo/r}^o \cdot \frac{N_{i+++}}{n_{i+++}^o} \dots\dots\dots (7)$$

$$w_{hvo/ri}^{1,hsize} = w_{ihvo/r}^{1,income} \cdot \frac{N_{+h++}}{n_{+h++}^{1,income}} \dots\dots\dots (8)$$

$$w_{ihvo/r}^{1,veh} = w_{hvo/ri}^{1,hsize} \cdot \frac{N_{++v+}}{n_{++v+}^{1,hsize}} \dots\dots\dots (9)$$

$$w_{ihvo/r}^{1,owner/renter} = w_{ihvo/r}^{1,veh} \cdot \frac{N_{+++o/r}}{n_{+++o/r}^{1,veh}} \dots\dots\dots (10)$$

These four successive adjustments constitute a cycle as represented by w^1 (cycle- 1). In each cycle, adjustments to the horizontal and vertical conditions are enforced proportionately, and are repeated in simultaneous steps, until the survey samples become stable with the satisfaction of all four sets of population conditions. Two functions for the proportionate adjustments of the horizontal and vertical conditions were developed in a ‘Visual Basic’ program. Data converged to less than 99% of the population figures after two cycles of operations (eight iterations) as presented in ‘Iterative Proportional Adjustment’ tables (attachment).

Person Weights

The subsequent weight, which is the person–level weight, indicates how many persons from the whole population (of the study area) are represented by each sample person data. Similar to the household weights, the person level weight is used to obtain representative statistics for person level analysis of the population, and is derived in the same way as the household weights. Hence, the person weight should be used to estimate all person-level data, such as, number of licensed drivers, annual person’s trips, persons

in the different age groups, gender of persons etc. For example, to get an estimate of number of persons 5 years and older, the initial person weight must be weighted (adjusted), so that their sums equals an estimate of the survey population of age 5- years and older. Also, using the control values (marginal) on several person features (e.g., age, gender, ethnicity), post stratification weight adjustments can be applied to the person data so that, sum of their weights in a specific sub-group agrees with the population estimate for that sub-group.

Trip Weight

The trip level weight is a function of the adjusted person weight. Depending on the data requirements for trips, the person weight can be subsequently weighted to get information on trips made by each person of the sampled data. For example, for travel day weight, the final person weight will be multiplied by 365 days to expand the person travel day to an annual total.

Conclusion

Various studies have been conducted in the past to alleviate bias from household travel surveys. Even though different agencies have their own way to adjust biased data, and each method has its own merit in its specific application, no definite standards are being followed yet in the adjustment process. As a result comparability between survey data is not viable. This problem has given rise to difficulties in establishing standards in the data assessment process. Also, it is established from past research that it is hard to get a perfect sample generated through a household travel survey, with the present social and economic conditions of the respondents, and the practices of survey conduct and design. Research is essential to get a better understanding on each of these specific areas to address the problem. As it is customary to have some level of bias in every survey, it would be more practical to pay specific attention on the data adjustment process.

The present study has considered the facts and ambiguities of past surveys to identify the issue. The study documented the practices of recent surveys to establish standards in the data adjustment process. These practices vary from survey to survey, although they have the same goal. Past survey reports have been reviewed to identify the variables that are liable to bias, so that special focus is given to these variables in the data adjustment process in future studies. It is also established that non-response bias is typically high for households that have low-income, zero-auto with more household members, and those owned their house. Therefore, these facts have been considered in post- stratification adjustment.

Due to lack of definite demographic information from the census, the post- stratification adjustments could not include non-telephone households. Most significant characteristic for identifying such households is the households' income (NPTS, 1995). The other factors related with households' income for this sub-groups would include number of people in the households, the numbers of workers and autos, type of housing units, households' owner/ renter status, and the density of the urban areas (McGuckin, 1999) etc. If sufficient demographics on this sub-groups of population were identified and

gathered, then they could be placed in an adjustment cell of the cross classified table in the low-income (<\$10,000- \$20,000) stratum during post stratification adjustment. This could adjust the weights for those households not covered (non-telephone) by the survey. Although, telephone non-coverage may not seriously bias population estimates, serious bias may occur when this sub-group of population (low-income, transit users) is the target of the survey.

The iterative proportional fitting procedures used in post stratification adjustment is simple and straightforward. The method has the advantage of converging quickly. The method can be extended for more variables.

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**Table 6: Cross- classified table of Phoenix data for household size x household income
X household vehicles x household's owner/renter status**

Household Income		1-person household				2-person household				3-person household				4+ person household				Total sample
		0- veh	1-veh	2- veh	3+ veh	0-veh	1-veh	2-veh	3+veh	0-veh	1-veh	2 veh	3+veh	0-veh	1-veh	2-veh	3+veh	
<\$10k	owner	17	36	1	0	5	8	5	0	0	2	2	0	0	7	5	1	89
	renter	65	35	0	0	18	15	4	1	10	15	5	1	13	8	4	0	194
\$10k-\$19.99k	owner	34	95	10	0	5	34	33	0	1	10	6	0	5	28	24	7	292
	renter	50	70	2	1	18	43	12	0	11	28	4	2	18	42	14	4	319
\$20k-\$34.99k	owner	15	169	24	0	0	81	71	10	1	12	28	4	5	43	57	23	543
	renter	33	88	8	1	15	49	29	4	3	22	11	5	7	47	26	6	354
\$35k-\$49.99k	owner	6	119	19	5	3	82	129	31	0	18	30	17	1	18	69	28	575
	renter	6	61	2	1	3	34	33	3	0	15	18	4	3	19	28	8	238
\$50k+	owner	4	129	32	3	3	77	370	88	0	8	120	75	1	14	188	118	1230
	renter	2	51	5	2	1	18	33	7	1	7	13	7	2	6	23	6	184
Total sampled		232	853	103	13	71	441	719	144	27	137	237	115	55	232	438	201	4018

Iterative Proportional Fitting Tables

Household Income	Status	1-person household			2-person household			3-person household			4+ person household			Total House Sampled	Total in Popul	
		0-veh	1-veh	2+veh	0-veh	1-veh	2+veh	0-veh	1-veh	2+veh	0-veh	1-veh	2+veh			3+veh
<\$10k	owner	17	36	1	0	5	0	0	0	2	2	0	0	7	1	283
<\$10k	renter	65	35	0	0	18	5	4	1	10	15	5	1	8	4	0
\$10k-\$19.99k	owner	34	95	10	0	5	34	33	0	10	6	0	5	28	24	7
\$10k-\$19.99k	renter	50	70	2	1	18	43	12	0	11	28	4	2	18	42	14
\$20k-\$34.99k	owner	15	169	24	0	81	71	10	1	12	28	4	5	43	57	23
\$20k-\$34.99k	renter	33	88	4	1	15	49	29	4	3	22	11	5	7	26	6
\$35k-\$49.99k	owner	6	119	19	5	3	82	129	31	0	18	30	17	1	18	69
\$35k-\$49.99k	renter	6	61	2	1	3	34	33	3	0	15	18	4	3	19	28
\$50k+	owner	4	129	32	3	77	370	88	0	8	120	75	1	14	188	118
\$50k+	renter	2	51	5	2	1	18	33	7	1	13	7	2	6	23	6
Sampled		232	853	103	13	71	441	719	144	27	137	337	115	55	232	438
Total Sampled		1301	3834	476	63	354	2179	3166	516	96	516	936	319	155	618	1018
Total population		277965	838233	103333	13333	71919	441333	638233	103333	13333	38323	51633	171919	55333	23233	43833

Household Income	Status	1-person household			2-person household			3-person household			4+ person household			Total own renter (sam)	Sample inc income	Total inc pop. inc
		0-veh	1-veh	2+veh	0-veh	1-veh	2+veh	0-veh	1-veh	2+veh	0-veh	1-veh	2+veh			
<\$10k	owner	4629.7678	9804.212	272.33922	0	1561.6961	2178.71378	1361.69611	0	544.67845	544.67845	0	0	1906.3746	1361.69611	272.33922
<\$10k	renter	17702.0495	9581.8728	0	0	4902.106	4085.08834	1089.35689	272.33922	272.33922	4085.0883	1561.6961	0	53833.9019	350110	77072
\$10k-\$19.99k	owner	675.17512	19489.46	2051.5221	0	1025.761	6975.17512	6770.02291	0	205.13221	1230.9133	0	1025.761	5744.2619	1082.63309	1436.0653
\$10k-\$19.99k	renter	10257.6105	14369.635	410.30442	205.1522	3692.7398	8831.54501	2461.82651	0	2256.6743	5744.2619	820.60884	410.30442	3692.7398	3821.13093	820.60884
\$20k-\$34.99k	owner	3701.88963	41707.957	5923.0234	0	19990.204	17522.2776	2467.9264	2467.9264	246.79264	246.79264	0	0	10612.084	14607.1086	5676.2308
\$20k-\$34.99k	renter	8144.15719	21717.753	1974.3411	246.7926	3701.8896	12092.8398	7156.98662	987.17057	740.37793	5429.43881	2714.7191	1233.9623	11592.234	1480.7539	4482.8996
\$35k-\$49.99k	owner	1460.1845	23960.326	4623.9176	1216.82	730.09225	19955.8549	31395.9668	7544.7866	0	4380.5535	7300.9225	4137.1894	243.36408	4380.5535	6792.1218
\$35k-\$49.99k	renter	1460.1845	14465.209	486.72817	243.5641	730.09225	8274.37884	8031.01476	730.09225	0	3650.4613	4380.5535	973.45633	730.09225	4633.9176	6814.1943
\$50k+	owner	1446.67841	46653.304	11573.409	1085.007	1085.007	27848.5149	133817.239	31826.874	0	2893.3522	43400.283	27125.177	561.66902	5063.5663	67932.7765
\$50k+	renter	723.338048	18445.12	1808.3451	723.338	361.66902	6310.04243	11925.0778	2531.6832	4701.6973	2531.6832	4701.6973	2531.6832	2170.0141	8138.38755	2170.0141
HH size after 1st		56301.0318	225517.87	29123.93	3720.474	17591.053	116732.357	221539.765	46360.372	6334.0583	34272.551	73366.266	37671.283	13278.886	5894.932	130649.106
Total population		314863	314863	314863	402223	402223	388223	388223	402223	151846	151846	151846	364118	364118	264118	364118

Household Income	Status	1-person household			2-person household			3-person household			4+ person household			Total sampled household by inc	Total income	Total house income by inc
		0-veh	1-veh	2+veh	0-veh	1-veh	2+veh	0-veh	1-veh	2+veh	0-veh	1-veh	2+veh			
<\$10k	owner	4087.2161	8655.2812	240.42448	0	1306.1751	2089.88021	1306.17513	0	616.6812	616.6812	0	0	2145.0652	1532.14658	306.42932
<\$10k	renter	15627.591	8414.8557	0	0	4702.2265	3918.52559	1044.9401	261.22502	3083.406	4625.109	1541.703	308.3406	3983.5811	2451.4345	1225.71726
\$10k-\$19.99k	owner	6157.7196	1706.539	1811.1094	0	983.9728	6900.7735	6903.98605	0	232.27192	2322.7192	1395.6315	0	1154.1608	6463.3005	5359.97184
\$10k-\$19.99k	renter	9055.547	1267.766	362.22188	181.1109	3542.1742	8461.86061	2361.44947	0	2534.9912	5303.6139	395.0877	464.54385	4154.9789	9694.9507	3231.65024
\$20k-\$34.99k	owner	3268.07453	3830.306	5228.9193	0	1973.1354	11599.7733	6865.17193	946.92027	279.41694	5335.0032	7825.5863	1397.0847	1388.4247	1940.452	1828.0415
\$20k-\$34.99k	renter	7189.76397	19172.704	1740.9731	217.8716	700.32291	1942.1868	30113.928	7236.8804	838.25081	6147.1726	3075.5863	197.0847	1943.7946	13051.192	719.8084
\$35k-\$49.99k	owner	1289.66917	2556.538	4082.0524	1074.224	700.32291	7927.09427	7003.56297	700.32291	0	4859.6326	8266.0544	4684.0755	273.82721	4928.8998	18894.0775
\$35k-\$49.99k	renter	12771.6378	15105.537	429.68972	214.8449	1040.7626	26713.0563	138361.3443	30839.184	0	4133.0272	4899.6326	1102.1666	821.48163	5202.717	7671.61888
\$50k+	owner	638.571829	16283.583	1546.4207	638.5719	346.92285	6244.6886	11448.4441	2438.4578	409.27919	2866.3543	5352.1295	2846.3345	813.88097	2441.6459	6517.92668
\$50k+	renter	49879.8116	195990	25710.97	3284.481	1873.8061	11972.781	212306.855	44780.102	7397.810	38003.107	83094.783	42651.181	14941.072	60102.562	147003.121
Sampled		27965	83823	10333	1333	71919	441333	638233	103333	13333	38323	51633	171919	55333	23233	43833
HH size after 2nd		8992	41383	46286	16123	8992	41383	46286	16123	8992	41383	46286	16123	8992	41383	46286
Sum by Vehicle		27965	83823	10333	1333	71919	441333	638233	103333	13333	38323	51633	171919	55333	23233	43833
Pop. by Vehicle		8992	41383	46286	16123	8992	41383	46286	16123	8992	41383	46286	16123	8992	41383	46286

Household Income	Status	1-person household			2-person household			3-person household			4+ person household			Total (sum/owner/renter)	Total sam. (sum/owner/renter)	Total hh (inc/pop)	
		0-veh	1-veh	2+ veh	0-veh	1-veh	2+ veh	0-veh	1-veh	2+ veh	0-veh	1-veh	2+ veh				3+veh
<\$10k	owner	3878.68726	8213.60977	228.13807	0	1239.5344	1983.2499	1239.53437	0	585.21826	585.21826	0	2035.5675	1453.9768	290.79536	21733.63594	79353
	renter	17590.8305	9471.9857	0	0	5292.9552	4410.79601	1176.21227	294.05307	3470.7635	5206.1453	1735.2818	347.07635	4484.0244	1379.6993	576.9132349	79353
\$10k-\$19.9k	owner	5843.60382	16237.717	1718.707	0	933.27302	6349.4175	6162.66434	0	2042.4246	2204.2146	3252.5288	0	1095.5788	6193.3373	533.3861	5102.5333
	renter	10093.1637	14270.429	407.72053	203.8633	3987.1651	9524.89452	2658.1101	0	2875.9638	7370.4401	1045.8057	322.90287	4676.9453	10913.3232	73377.46893	128340
\$20k-\$34.9k	owner	3101.33811	34901.743	4062.141	0	18196.0243	15950.3028	2246.5215	3184.9338	7424.5121	1360.6446	1317.8786	11331.253	15020.984	6049.9039	135661.364	221373
	renter	8092.98884	21581.304	1961.9367	245.2421	3997.0445	13057.0121	7277.6193	1065.8785	943.55733	6709.4924	3459.7102	1575.5855	2197.8667	14690.768	8175.8076	1875.4171
\$35k-\$49.9k	owner	1223.3015	24262.191	3673.787	1019.418	664.93534	18165.5567	28877.5231	6867.4666	4706.1139	259.85661	4077.4189	17930.059	225.985	131793.1819	97306.2844	179256
	renter	1451.01041	14751.039	485.67014	241.8531	788.30315	8954.1032	8671.3346	798.30315	4652.2449	5382.6959	1240.5986	924.68149	3536.3161	8650.30657	2465.8173	65462.1097
\$50k+	owner	1211.94419	39086.49	9695.8753	908.9881	987.66791	25536.1451	121812.376	2871.595	0	3108.7012	46650.518	29144.074	386.17895	5406.503	72901.642	435071.8303
	renter	718.793438	18329.231	1796.9636	718.7954	390.50521	7029.09382	12886.671	2733.5965	460.02963	3276.4044	5991.9681	3226.4444	916.12711	2748.3813	10535.4618	2748.3813
Sampled hh		53505.7014	201266.67	25128.983	3338.14	1824.506	11901.09	206862.348	42967.331	8236.7898	4111.556	81622.659	41559.452	16248.673	66532.047	144575.508	68859.124
Pop. by Veh. 2d		283069			381112			172530					296233				
Pop. by veh		96073	421901	458188	156724	96073	421901	458188	156724	96073	421901	458188	156724	96073	421901	458188	156724
Total pop. by veh		78758	438513	454034	161581	78758	438513	454034	161581	78758	438513	454034	161581	78758	438513	454034	161581

Household Income	Status	1-person household			2-person household			3-person household			4+ person household			Total (sum/owner/renter)	Total sam. (sum/owner/renter)	Total hh (inc/pop)	
		0-veh	1-veh	2+ veh	0-veh	1-veh	2+ veh	0-veh	1-veh	2+ veh	0-veh	1-veh	2+ veh				3+veh
<\$10k	owner	3179.44101	8571.0979	226.0956	0	1016.1361	7061.344	1728.29657	0	608.20075	579.91259	0	2115.7163	1440.7983	299.90734	7106.25	77072
	renter	1420.4235	884.9372	0	4239.0189	4584.4675	1165.54656	303.166	2845.2363	5411.1259	1719.6485	357.83252	897.8798	2688.0487	1567.9726	5902.54661	362781
\$10k-\$19.9k	owner	4790.42531	16970.07	1703.125	0	765.9419	6599.4454	6106.79272	0	180.05945	2291.0057	1310.5385	0	807.87093	675.0475	2309.6005	1380.9069
	renter	8536.07489	14532.315	404.02004	210.1812	3388.5682	9899.9293	2634.0128	0	2357.6718	7608.8842	1056.3243	359.10804	3834.0384	11342.58	3604.65184	1071.5326
\$20k-\$34.9k	owner	1189.49838	15322.784	479.28511	0	18193.3091	15805.695	2316.143	217.37181	33072.038	7557.204	1093.5148	1080.122	11777.412	14884.3205	6248.735	126778.1327
	renter	1002.8236	25217.041	3838.6666	1051.01	544.81548	18880.8104	28318.4341	773.50231	7191.8668	3428.3439	1621.3315	1795.6512	15269.204	8055.12881	1933.5578	770625
\$35k-\$49.9k	owner	2542.39138	36317.245	4917.1535	0	1002.8236	25217.041	3838.6666	1051.01	544.81548	18880.8104	28318.4341	773.50231	7191.8668	3428.3439	1621.3315	1795.6512
	renter	1189.49838	15322.784	479.28511	0	18193.3091	15805.695	2316.143	217.37181	33072.038	7557.204	1093.5148	1080.122	11777.412	14884.3205	6248.735	126778.1327
\$50k+	owner	993.551266	40625.488	907.9693	971.1384	899.66296	26548.2838	120708.007	29869.445	0	3221.1037	4607.7059	30047.272	316.57887	5019.3819	71943.0438	46981.338
	renter	589.247068	19050.951	1780.6919	741.0694	320.12542	7305.8883	12769.8395	2818.2599	3771.85004	3325.4829	5937.6441	3236.4344	751.01578	2836.5966	14329.9457	2633.5558
Sampled hh		45698.5462	209160.2	24901.16	3441.591	14986.675	117450.413	204966.903	44298.943	3752.2935	42730.29	80882.656	12347.412	13320.215	69172.479	104362.783	70993.122
Pop. by Veh. after 4		78758	438513	454034	161581	78758	438513	454034	161581	78758	438513	454034	161581	78758	438513	454034	161581
Total pop. by veh		78758	438513	454034	161581	78758	438513	454034	161581	78758	438513	454034	161581	78758	438513	454034	161581

Household Income	Status	1-person household			2-person household			3-person household			4+ person household			Total (sum/owner/renter)	Total sam. (sum/owner/renter)	Total hh (inc/pop)	
		0-veh	1-veh	2+ veh	0-veh	1-veh	2+ veh	0-veh	1-veh	2+ veh	0-veh	1-veh	2+ veh				3+veh
<\$10k	owner	1302.00809	8668.016	234.8529	0	98.609581	200.04039	1275.90804	0	59.027856	56.278446	0	205.31688	139.82019	29.094005	14469.8275	77072
	renter	14979.4479	10236.549	0	874.06593	923.50775	1210.72778	314.91738	573.15225	1090.0235	346.41074	720.08769	740.47935	577.74764	275.41075	32204.53038	36323
\$10k-\$19.9k	owner	837.28297	16912.051	1697.2485	0	125.92824	1085.70198	6085.72175	0	29.727092	376.90424	215.60311	0	147.71413	1048.7903	857.066665	260.08273
	renter	8327.8297	14781.138	402.63597	209.4559	1116.2133	3380.81767	2624.92285	0	805.13127	2598.4277	353.90389	184.0495	1309.3209	3873.4815	1230.9832	365.92751
\$20k-\$34.9k	owner	6553.10265	22196.722	1923.8398	250.201	5534.00619	15640.5798	2291.9473	63.602659	967.6876	2152.2087	319.96081	316.0421	3446.0232	6355.13066	1828.7006	80235.85596
	renter	993.563666	24984.461	3803.2017	1041.3	142.30306	4931.57245	29056.8041	7014.8809	1277.74036	2030.3218	1197.0235	1089.4318	9274.1255	4891.2613	1774.3816	74167.97464
\$35k-\$49.9k	owner	1178.0877	15191.127	4724.8707	247.0262	330.37718	9034.68224	8513.33009	805.22455	0	2631.7044	2099.1239	693.48319	410.99328	3300.241	4638.8477	1378.3671
	renter	997.265664	40716.986	9643.2988	940.6533	529.55453	1758.3315	12158.145	2980.833	0	2153.1073	30792.562	3023.314	210.96613	3744.7209	47942.8482	31308.07
\$50k+	owner	591.444457	19121.975	1767.3223	743.833	43.82845	10106.1702	13817.4601	2838.9606	522.6782	4638.062	8213.5258	4601.4459	10388.7777	5951.2507	14441.5427	5919.6485
	renter	44235.1865	208997.17	246353.554	532.4689	5680.0421	36997.5833	209901.106	44323.994	2464.0976	8243.49201	28076.109	5319.4321	30691.87	85411.5111	42232.29	835032.2612
Sampled hh		281489	281489	281489	381602	381602	381602	381602	381602	381602	381602	381602	381602	381602	381602	381602	381602
Pop. by hh size		277965	277965	277965	383823	383823	383823	383823	383823	383823	383823	383823	383823	383823	383823	383823	383823
Pop. by Veh. 5th		79621	437881	453883	161661	79621	437881	453883	161661	79621	437881	453883	161661	79621	437881	453883	161661
Pop. by veh		78758	438513	454034	161581	78758	438513	454034	161581	78758	438513	454034	161581	78758	438513	454034	161581

Household Income	Status	1-person household			2-person household			3-person household			4-person household			Sample own/ren	Total own/ren	Total owner/rent/prop	Total househ. by income as inc/prop
		0-veh	1-veh	2-veh	0-veh	1-veh	2-veh	3+veh	0-veh	1-veh	2-veh	3+veh	0-veh				
<\$10k	owner	3261.54154	8756.2946	231.91313	0	1067.1992	2164.93111	1290.0212	0	626.33869	597.16708	0	0	2302.5139	1499.90366	312.10698	764563
	renter	14791.9181	10698.521	0	4557.0643	4814.84709	1224.11996	318.40077	2929.8924	1572.1336	1770.8143	368.47932	886.28166	2985.7108	1425.28609	0	5481.86333
\$10k-\$19.9k	owner	4714.13148	16700.327	1676.0004	0	771.24842	6649.38981	6153.0752	178.51031	2263.2988	1294.6903	0	3856.72816	6566.8912	3709.947	1578.8843	125348
	renter	8222.99306	14596.091	397.59533	206.8337	3293.32	9974.89832	2653.95781	2329.12568	7516.0329	1023.7921	532.58864	3629.133	11328.068	3600.03997	1070.1617	70575.46922
\$20k-\$34.9k	owner	2484.33628	34488.256	4804.8707	0	18922.7497	15813.5844	2317.2991	113.23557	3244.2887	717.2047	1072.707	1071.1669	1679.768	14760.9173	1096.0279	123287.2922
	renter	6482.91321	21918.838	1899.755	247.0683	3278.3036	13577.8951	7661.38197	1099.4244	758.7838	7055.0171	3363.108	1590.4802	1778.7804	15143.61	7986.36186	1917.5072
\$35k-\$49.9k	owner	981.125045	24671.677	3755.5889	1028.264	545.72568	18913.2853	78567.1478	1099.4244	0	4904.883	6534.599	1501.1555	211.51469	4827.166	17641.262	7448.5395
	renter	1163.75486	15600.947	468.91236	243.9336	647.54086	6931.84881	8607.50029	814.13135	0	4749.2019	5433.4369	1263.2389	253.66121	6043.8055	1891.56339	3534.2347
\$50k+	owner	984.771372	40366.694	9523.6668	928.877	821.6716	26379.0736	122498.307	30314.458	0	3215.027	45977.846	28987.788	318.45168	5632.6249	72369.0363	47292.27
	renter	584.04081	18882.384	1764.955	724.5208	324.87341	7414.21652	12592.2574	2860.0503	375.96999	3336.2972	5988.1005	3309.8353	275.45862	2073.4955	10501.7061	2850.3185
Sampled his		45871.532	20638071	24522.659	3389.498	15306.775	118475.158	207228.295	44814.273	6785.5188	42383.676	80220.259	42529.3	13440.578	69102.653	144774.54	71157.771
Hh size after 7h		27965	27965	27965	27965	38823	38823	38823	38823	171919	171919	171919	297179	297179	297179	297179	297179
Pop. by hh size		79204	436340	454449	161891	79204	436340	454449	161891	79204	436340	454449	161891	79204	436340	454449	161891
Sample by veh 6h		78758	438313	454034	161581	78758	438313	454034	161581	78758	438313	454034	161581	78758	438313	454034	161581
Pop. by veh		78758	438313	454034	161581	78758	438313	454034	161581	78758	438313	454034	161581	78758	438313	454034	161581

Household Income	Status	1-person household			2-person household			3-person household			4-person household			Sample own/ren	Total own/ren	Total pop. own/ren	Total househ. by inc. by inc/prop
		0-veh	1-veh	2-veh	3+veh	0-veh	1-veh	2-veh	3+veh	0-veh	1-veh	2-veh	3+veh				
<\$10k	owner	3234.5813	6884.6268	229.9966	0	1058.3799	2147.04012	1270.56046	0	621.18346	592.23209	0	0	2184.3123	1487.50845	309.23773	77473
	renter	15053.3238	10276.301	0	4657.2895	4899.61051	1245.67009	324.06668	2981.4719	15670.2287	1801.9807	374.96625	3864.0065	3038.2751	1448.33677	0	58644.5173
\$10k-\$19.9k	owner	4675.17389	16562.315	1662.1499	0	764.47483	6594.4924	6102.18881	0	1771.0351	1244.3549	1283.591	0	889.5176	614.2752	3159.99715	13638304
	renter	8367.7355	14853.049	404.9481	210.425	3351.2976	10150.5023	2700.67966	0	2370.1391	7649.202	1041.8156	541.96465	3906.3434	1157.4994	3663.4721	189100014
\$20k-\$34.9k	owner	2463.80572	35194.962	4765.1632	0	18766.372	15862.9009	2298.1489	0	4747.9791	7971.5667	4463.978	209.76702	4787.2743	17495.9548	131330.1863	221373
	renter	6997.04226	22304.71	1933.1994	251.4182	3336.0158	13816.9285	7796.25348	1118.815	172.14188	3217.2778	3422.3142	1618.4799	1810.0951	15409.19	8126.98851	1951.2641
\$35k-\$49.9k	owner	973.017026	24467.79	3724.527	1019.766	541.24238	18756.8989	28132.7216	823.4638	0	4852.8097	5529.0964	1278.3545	765.91152	6150.2042	8641.05391	2568.6728
	renter	1184.24229	15265.033	4771.6277	248.228	638.27704	9465.60407	8759.0183	328.4638	0	3188.458	45597.885	29650.692	315.81999	5605.9116	71770.9863	46868.719
\$50k+	owner	976.63418	39933.731	9444.5881	921.2008	814.88131	26518.1008	12.485.938	30661.956	0	3188.458	45597.885	29650.692	315.81999	5605.9116	71770.9863	46868.719
	renter	594.321869	19215.004	1796.0278	747.4518	330.9268	754.74078	13182.3795	2910.4003	382.58879	3395.5402	6012.1102	3368.1525	768.75816	2924.0823	10686.8844	2900.472
Sampled his		44118.9039	206757.52	24437.22	3398.54	15403.311	118660.328	206372.171	44575.652	6894.8412	42763.689	80010.496	42360.41	15612.578	69524.262	14519.713	70786.042
Hh size after 7h		27965	27965	27965	27965	38823	38823	38823	38823	171919	171919	171919	297179	297179	297179	297179	297179
Pop. by hh size		80120	437706	453940	161121	80120	437706	453940	161121	80120	437706	453940	161121	80120	437706	453940	161121
Sample by veh 7h		78758	438313	454034	161581	78758	438313	454034	161581	78758	438313	454034	161581	78758	438313	454034	161581
Pop. by veh		78758	438313	454034	161581	78758	438313	454034	161581	78758	438313	454034	161581	78758	438313	454034	161581

Household Income	Status	1-person household			2-person household			3-person household			4-person household			Sample own/ren	Total own/ren	Total pop. own/ren	Total househ. by inc. by inc/prop
		0-veh	1-veh	2-veh	3+veh	0-veh	1-veh	2-veh	3+veh	0-veh	1-veh	2-veh	3+veh				
<\$10k	owner	3179.60177	8706.6387	230.04422	0	1040.388	2150.99862	1279.62538	0	621.32774	592.23472	0	0	2188.3395	1487.81648	310.41143	77072
	renter	14796.4418	10295.248	0	4558.4579	4908.64394	1245.92804	324.97112	2950.7884	5660.6829	1802.3619	376.05678	3827.8356	3043.8747	1448.63668	0	55239.88561
\$10k-\$19.9k	owner	4595.69827	16592.851	1662.094	0	751.87234	6606.59743	6103.45242	0	1740.02559	1248.7333	1284.2569	0	874.199664	6325.9168	5161.06566	1570.3068
	renter	8225.50784	14880.433	404.6786	211.0759	3294.3272	10169.2169	2701.2389	0	2329.83091	7663.3409	1042.0313	443.51196	3830.3041	11548.747	5664.17382	1092.1105
\$20k-\$34.9k	owner	2421.92225	35259.851	4766.15	0	18800.977	15866.1485	2304.7101	207.87845	3225.4099	7159.0438	1066.8794	1044.256	11604.602	4641.9444	6163.2625	124351.0497
	renter	6484.89584	22345.834	933.5897	282.136	3279.3052	13842.4028	7997.8719	1122.0092	759.01586	7192.4541	3423.0239	623.1007	1729.3744	1843.76	8138.6144	1956.835
\$35k-\$49.9k	owner	956.67622	24512.001	3725.234	1022.678	532.04175	18791.5772	28138.5472	7053.9438	0	4775.7633	5753.0746	4476.7026	206.20109	4796.1006	7189.5778	7007.8956
	renter	1164.11078	15295.171	4722660.6	647.5383	946.05384	8760.84262	830.82907	0	4841.72	1530.2353	1282.0042	752.8914	6101.5434	8642.84236	2576.0064	66093.00372
\$50k+	owner	960.03138	40007.357	9446.328	923.808	801.02873	28666.9923	12151.137	30147.782	0	3194.3365	4560.2328	29753.345	310.45121	5616.2473	71783.8303	47002.529
	renter	584.218694	19250.451	1796.3997	749.3857	324.92726	7558.6505	15901.103	2918.7095	576.04097	3401.8066	6013.3552	3377.7683	755.68966	2929.4754	10688.2973	2908.7781
Sampled his		45368.9064	207338.72	24442.28	3408.243	15529.933	118879.103	206414.906	44702.915	6771.6324	42842.533	80027.064	42481.349	13381.171	69652.444	145149.249	70988.135
Hh size after 7h		27965	27965	27965	27965	38823	38823	38823	38823	171919	171919	171919	297179	297179	297179	297179	297179
Pop. by hh size		78758	438313	454034	161581	78758	438313	454034	161581	78758	438313	454034	161581	78758	438313	454034	161581
Sample by veh 8h		78758	438313	454034	161581	78758	438313	454034	161581	78758	438313	454034	161581	78758	438313	454034	161581
Pop. by veh		78758	438313	454034	161581	78758	438313	454034	161581	78758	438313	454034	161581	78758	438313	454034	161581

Land Use Forecasting Methods in Ohio

Nick Gill, *Mid-Ohio Regional Planning Council* and David Schmitt, AICP,
Burgess & Niple

Abstract. Land use data is an important part of travel demand forecasting. The data is a set of socio-economic characteristic used to develop trip productions and attractions. It serves as the “backbone” of all travel demand forecasts. At a meeting in 2000, several Ohio Metropolitan Planning Organizations (MPOs) gave presentations on their land use forecasting methodology. It was apparent there was a wide variation in the MPOs in land use forecasting methods and variables. Consequently, the OTDMUG surveyed the 16 MPOs to record the methods, variables, and review processes the MPOs use in forecasting land use variables.

This paper provides the findings of the survey including:

- Summary of Ohio’s 16 MPOs
- Description of development of a ‘typical’ land use forecast
- Description of common & unique land use variables
- Types of software and procedures used
- Local Review process
- Other customers of land use data

The OTDMUG feels that this information would be valuable to other states and organizations.

Oregon's Transportation and Land Use Model Integration Program: Recent Progress

John Douglas Hunt, *University of Calgary* and Rick Donnelly, *PBConsult Inc.*

Abstract. The Oregon Department of Transportation initiated an ambitious program in 1996 to develop a set of state-of-the-art integrated land use-transportation models. The first phase of the program revolved around the adaptation of an existing integrated modeling platform (TRANUS), as well as the development of an urban prototype (UrbanSim). Subsequent work has focused on the application of the prototypes, as well as the specification and development of a new set of models. This presentation will summarize the progress to date in the ODOT program, with particular emphasis on recently completed work:

- Recent applications of the prototype models to actual ODOT policy and legislative studies.
- The design of the second generation land use-transport models, to include a brief description of each component.
- Guidelines for and experiences with model validation, both for individual components and the system as a whole.

The presentation will conclude with a discussion of anticipated near-term model development and implementation issues.

A Macro-Micro Approach in Developing the Louisiana Statewide Model

Tom Cooney and Supin L. Yoder, *Wilbur Smith Associates*

Abstract. With the desire to derive maximum benefit from increasingly scarce transportation dollars, the Louisiana Department of Transportation and Development (LDOTD) has invested in development of a statewide travel demand forecasting model. This model is used to forecast auto and truck traffic on rural portions of the state highway system. Like traditional urban models, this model is used to evaluate statewide transportation projects and issues, and to assist in developing and maintaining LDOTD's Statewide Long Range Transportation Plan. The state of the art statewide modeling approach and techniques were developed and applied for the Louisiana statewide auto passenger model. Several unique features are highlighted below:

- Macro-Micro modeling framework, allows state officials to evaluate impacts of transportation projects that lie within or outside Louisiana. The two inter-related nationwide macro model and Louisiana-only micro model have different network coverages, zone structures, calibration techniques, modeling procedures, and calibration and validation data sources.
- Activity based zone structure allows accurate prediction of intercity auto movements. The two-tiered macro model zone structure was deployed based on American Travel Survey information. For the micro model, a Census Place and Block Group-based zone structure was designed to reflect population concentrations where the activities occur. Special treatments for the centroid connectors were also applied to reflect the settlement patterns observed in Louisiana.
- Travel market segmentation technique allows better understanding and prediction of each travel component. Trips are distinguished by travel distance, trip purposes and nature of the trip such as interstate vs. intrastate trips. For example, the model would allow producing interstate short distance home-based work trips as well as intrastate long distance tourist trips on the Louisiana highway system.
- Claritas lifestyle cluster trip making information allows developing trip rates based on National Personal Transportation Survey (NPTS) data and "contextual density" of human settlements at the census block-group level, resulting in much more accurate trip rates as compared with MSA/non-MSA rates, or urban/rural rates typically used in other statewide models.
- Applying mid-point link attributes between intersections for calculation of travel impedance allows the capturing of major movements between rural intercity travels without being influenced by small-scale development around intersections.
- Preservation of Linear Reference System and Linkage to LADOTD legacy databases in network design allows for automatically updating network attributes from the LADOTD's Surface Type Log file or Highway Needs Inventory file that are updated frequently by DOT staff.

We have learned that although methods and techniques for statewide models have not matured as much as those found in urban models, many opportunities exist for innovative ideas and experiments. The above methods and techniques have demonstrated that a good statewide model can be developed that does not require the use of a synthetic matrix balancing method. This method, commonly used by the other statewide models, disconnects the model output from the drivers of trip making and economic activities, and is insensitive to transportation network changes.

A Synthesis of Zonal Structures and Demographics for Statewide Models

Thomas A. Williams, *Wilbur Smith Associates*

Abstract. Many state transportation agencies have developed statewide applications of travel demand models in the past decade, and many more have plans to enter this relatively new field of model application. This paper is a discussion of statewide modeling, focusing on zonal geography and demographic development in the context of the purpose and need for, and application of, statewide models. The paper is a synthesis describing 5 statewide model zone structures and associated demographics developed in Texas, Kentucky, Louisiana, Mississippi, and Virginia. The paper covers the state of the practice in developing zone structures and demographics for statewide models in these states. For each application, the paper examines various experiences with zone size, data sources, hardware performance, the relationship of zone structure with the purpose of the statewide model, the relationship between modal (freight vs. auto) requirements and zone structure, and other issues. Included is a discussion of the theory, accuracy, purpose and need for statewide models, and data collection needs, in the context of the selection of zone structures and the development of demographics on a statewide basis. The paper examines the selection of zone structures in the 5 applications related to population and employment sources and development methodologies. Lessons learned, along with “what worked/what didn’t work”, are also discussed. The paper recommends practical data requirements and availability for states desiring a statewide application or updating and improving existing statewide application procedures.

Ohio's Interim Statewide Travel Demand Forecasting Model

Gregory T. Giaimo, *Ohio Department of Transportation*

Abstract. In the late 1990's ODOT began development of a statewide travel demand forecasting model. A consultant was hired to develop a model scope within broad guidelines provided by ODOT. This first phase of development included a user needs study which involved both senior management as well as technical staff of ODOT. The results indicated a focus on truck/freight flows, economic vitality and traditional congestion measures. To address the needs, the model proposed by the consultant was quite ambitious. When complete in 2005, it is envisioned that this final model will cover not only the multi-modal transportation system of the state but will also model the economic and land use interactions of the state and beyond.

To produce results before 2005, an interim model capability has been developed concurrently. This model is being developed from independent data sources and thus will also provide a validation tool for the final model. The consultant developing the final model was tasked with producing 3 products for input to this model, a network of the highway system in Ohio and base year origin-destination car and truck trip tables. The network was developed from Ohio's Roadway Information Database and will also serve as the Ohio portion of the highway network in the final model. The base year trip tables were developed based on 4 sources. Trip tables from 13 MPO's in Ohio were compressed to the statewide zones system to give intra-urban travel. Roadside origin-destination surveys conducted at 700 locations around the state give all travel into/out of urban areas and into/out of the state. A quick response trip generation/distribution method is used in conjunction with traffic counts and a matrix estimation process to give all rural to rural travel.

The zone system used for this model is very coarse. Many of these large zones contain numerous network roads, which has necessitated two special techniques. First, only counts on links crossing zone boundaries are used in the matrix estimation process used to develop the base year trip table. This prevents the adjustment process from attempting to match the higher volume links passing through small towns completely contained within a zone. Second, the assigned volumes are subtracted from the counts (on all links) to produce a residual volume. This residual is then adjusted to represent the local travel not modeled by the trip table and is preloaded to the network. It is iteratively calculated until the result has stabilized.

ODOT has also developed a set of population and employment data using the 2000 Census and data from Ohio's ES 202 file. Using this, a simple regression generation/gravity distribution model was developed for both cars and trucks. A set of forecast year population and employment is also being developed (based primarily on MPO forecasts) which will allow model runs on the forecast year to be made.

A State-of-Practice Link Free-Flow Speed Estimation for the Indiana Statewide Travel Demand Model

Kyeil Kim, PhD and Vince Bernardin AICP,
Bernardin, Lochmueller & Associates, Inc.

Abstract. Free-flow link speed is one of the factors that determine travel impedance on the network. It is the “starting point” for all destination, mode and route choices in the travel demand modeling process. Many travel demand models use posted speed limits as a surrogate for free-flow link speeds in the network skim and trip assignment processes. This practice usually under-represents the true free-flow input to the travel model; thus, these speeds may result in a significant overestimation of travel times. In other cases, free-flow speeds are often based on highly simplistic speed tables that overlook real-world variability.

This paper presents a recent practice to estimate correct link free-flow speed for the Indiana Statewide Travel Demand Model based on travel speed data collected from field surveys. As part of the I-69 Evansville to Indianapolis Environmental Impact Study in 2002, the surveys were undertaken for a total of 64 locations in the southwestern Indiana by using NU-METRICS[®] traffic analyzers that were installed on the road surface to instantly record travel speed data on the vehicles passing over. For each survey location, roadway characteristics such as functional classification, posted speed limit, number of lanes and terrain type were identified. In addition, a median speed for the location was estimated from the collected speed data. These data were then filtered to obtain the data that represent free-flow conditions based on criteria specified in the Highway Capacity Manual (HCM).

For the selected data, three tiers of statistical analyses were implemented to come up with actual free-flow speed in relation to the roadway characteristics. At tier 1, in order to test if functional classification makes significant difference in free-flow speed, the One-Way Analysis of Variance (ANOVA) technique was applied to datasets of functional classification and speed. At tier 2, any possible relationships between speed by functional classification and terrain type were investigated using a Non-Parametric Cross Tabulation technique. At tier 3, difference in speeds between 2-lane 2-way road and multilane road were identified from the survey data.

The tiered statistical analyses produced varying free-flow speed by area type, functional classification, posted speed and the number of lanes of the roadway. The analyses explicitly showed “speed differential” between the posted speed limit and actual vehicle travel speed over the posted speed in free-flow conditions. This exercise indicated that the mean free-flow speed is on the average 4.94 mph higher than the posted speed limits for all facilities, and 5.36 mph over the posted speed limit for rural interstate.

Applications of TP+/VIPER and GIS Software to the Development of the California Statewide Travel Model

Richard Dowling , Michael Aronson, David Reinke, and Damian Stefanakis
Dowling Associates, Inc.

Abstract. The California Department of Transportation (Caltrans) has developed a new multimodal statewide travel model that is a product of a unique collaborative effort between Caltrans staff and Dowling Associates. The model was developed through a series of classes taught by Dowling Associates on TP+/VIPER software and on travel demand modeling. Caltrans and consultant staff worked together to complete each component of the model through a set of class assignments. GIS tools were used extensively to develop and maintain the networks, zone system, and socioeconomic database for the model. Caltrans headquarters staff will use the model to respond to management and legislative requests for information on statewide and regional trends in transportation demand, supply, and operations. At the local level, Caltrans district staff will use the model to provide traffic forecasts for state highway facilities. The model also contains provision for linking to a separately developed statewide goods movement model. Ultimately, the model will be the key component of a centralized statewide travel data warehouse that will also incorporate data from regional transportation planning agency (RTPA) models, and in return provide forecasts of interregional travel to the RTPAs for use in their local forecasts.

Lessons Learned while Implementing a Program for Access Management in Texas

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Texas Transportation Institute

Abstract. The Texas Department of Transportation (TxDOT) recently sponsored research through the Texas Transportation Institute (TTI) to provide recommendations for implementing a comprehensive access management program with the State. The research includes a provision to produce an *Access Management Guidebook for Texas* for use by planners and engineers when planning, designing, and reviewing highway projects and access requests.

This paper describes some of the lessons learned in the research related to access classification, access spacing criteria, median alternatives, and the overall implementation of the program. Specifically, in terms of access classification, considerations include what type of access classification system (if any) is necessary to develop a successful program. For access spacing and median alternatives, lessons learned were related to what unsignalized access (driveway) spacing criteria and median opening guidelines are most applicable for adoption in Texas and why. Lastly, in terms of the lessons learned in the overall implementation of the program, several questions have been raised throughout the development of the program that have led to localized changes to the program that have strengthened the program overall.

This paper presents the results of these and other lessons learned, describes the background of access management, and outlines selected alternatives used in existing access management programs in other states. Finally, the paper provides the current status of the comprehensive access management program in Texas. The research and experiences that have emerged as a result of this project are expected to be useful to engineers and planners not only within Texas, but also in other states that are developing or modifying comprehensive access management programs.

New Developments in Traffic Safety Planning: The Metropolitan Houston Traffic Safety Program

Ned Levine, PhD, *Houston-Galveston Area Council*

Abstract. In this paper, I will discuss the traffic safety program of the Houston-Galveston Area Council (H-GAC), the Metropolitan Planning Organization (MPO) for the eight counties around Houston. The program has six basic components, partly modeled on the Federal Hazard Elimination Program. First, there is a GIS-based crash information system. The purpose is to identify the location of crashes and to display them on maps. H-GAC is one of the few MPO's in the country to have developed such a system. The advantage of a GIS-based system is that it allows systematic spatial analysis of all crashes and the prioritization of projects.

Second, using these data, we are identifying single locations where there are many crashes ('hazardous locations') and small areas where a number of crashes occur on a set of interconnected streets ('hot spots'). Using a software package that I developed for the National Institute of Justice, *CrimeStat*, we are able to identify both single locations and small areas that have either a high number of crashes or a high number relative to vehicle miles traveled (VMT). We are paying particular attention to hot spots involving pedestrian and bicycle crashes. Among some of our earlier findings are that many pedestrian and bicycle crash hot spots occur in low income communities and that the majority of severe injury or fatality crashes occur on local roads, not state managed roads.

Third, once the hot spots are identified, we work with local governments to improve safety at these locations. The partnership is with the local government, the state DOT (Texas Department of Transportation), the County (if there are county roads involved), the local police department, and other interested organizations (e.g., redevelopment agencies). To date, we have initiated projects in four hot spot locations. Three of these are pedestrian hot spots (where there are also a lot of vehicle-to-vehicle crashes) and one is a parkway that passes through multiple strip malls with access problems.

Fourth, we sponsor an engineering study to examine the actual crash patterns as well as traffic flow and access issues that affect safety. Fifth, we help the local government fund the implementation of the recommended improvements. Sixth, and finally, we are working to improve safety awareness among our constituent members by making presentations, co-opting them into safety projects, and, eventually, by developing safety courses that we will give to our members.

Downtown Brooklyn Traffic Calming Project

Seth Berman, *New York City Department of Transportation*

Abstract. In New York City, Downtown Brooklyn is a major cultural and institutional center that serves as a gateway to Manhattan. This diverse neighborhood contains educational, institutional and cultural attractions and historic residential communities where traffic intrusion is a major quality of life concern. Through traffic bound for Manhattan often uses local streets as an alternate route to the river crossings exacerbating neighborhood traffic conditions. In response to these community concerns, elected officials provided funding to initiate a multi-million dollar effort to develop an areawide traffic calming plan. This project was the first large-scale traffic project conducted in the City and covers an area of approximately five square miles. The first phase of the project will be completed in fall 2002 and includes community outreach, data collection, interagency coordination and implementation of a pilot program to test traffic calming measures. An areawide traffic management plan has been developed based on pilot program findings and community input.

A Scope of Work/Request for Proposals was developed by a Task Force of community representatives, elected officials, advocacy groups and the Department of Transportation. A consultant selection committee was formed, and unique to this project, included local residents designated by the elected officials who funded the project.

Community outreach was a key component throughout the project. Open Houses, Citizen Working Groups, Community Board meetings, and Task Force meetings were held throughout the project. These sessions identified local concerns, developed community "aspirations" for streets in their neighborhood, discussed potential solutions and policy issues, and provided input to the design and location of pilot program treatments.

The consultant working in conjunction with the community and the Department developed a Street Management Framework to classify streets not only by their traffic carrying function, as traditionally done, but by the activities that take place on them and the community functions that they serve. Based on a model developed for Denmark, streets were defined as either living, community or travel streets. This framework was a key element in developing the pilot program and areawide strategy. Many residents and merchants emphasized that major arterials that have a traffic carrying function should be made safer, more aesthetically pleasing and more pedestrian friendly.

Based on community input and discussions with Department engineers and planners, the consultant developed a series of pilot program treatments including a raised intersection, gateway treatments, neckdowns, a colored, textured bicycle lane, an all-pedestrian phase, a leading pedestrian indicator, a midblock crossing, and a raised median. There were discussions regarding the design of treatments with agency engineers recommending a more conservative approach while advocacy groups and some residents supported more aggressive treatments. The treatments have been monitored with surveys, videotaping and data collection.

The consultant has developed an areawide plan with specific strategies for streets and corridors within the study area. The plan is being modified based on community input and findings from the pilot program. The plan will serve as a basis for operational changes by the department and major improvements to be funded in the City's Capital Plan.

NCHRP-255 Alive and Well

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Abstract. The use of travel demand forecast models for project planning has increased over time. These models generate travel demand projections based on land-use forecasts and the planned transportation infrastructure. These projections are utilized by both public agencies and private funding organizations for determining project feasibility. Most travel demand models produce projections of traffic that are not directly suitable for project planning needs. Raw model output often needs to go through an additional post-processing step.

The recently completed I-270/US 15 Multi-Modal Corridor Study was undertaken to investigate options that will relieve congestion and improve safety conditions along the I-270/US 15 Corridor. The I-270/US 15 corridor provides an essential connection between the Washington, D.C. metropolitan area and western Maryland. It is an important corridor for carrying local and long distance trips, both within and beyond the corridor. For this multi-modal corridor study weekday average peak hour traffic forecasts were developed for a wide range of land-use scenarios and multimodal build alternatives.

A series of procedures, outlined in NCHRP-255, *Highway Traffic Data for Urbanized Area Project Planning and Design*, were applied to refine the raw regional travel demand forecast model output. These procedures were applied in order to compensate for the model's bias and the limits of the macro-level assignment algorithms. They were used to formulate peak hour traffic projections as well as the data required for the environmental impacts analysis. The results of this effort are being used for evaluating the proposed multi-modal highway planning and design improvements.

The freeway forecast was just part of an integrated system forecast where volumes feeding into the system had to be balanced. In order to develop this level of detail along a 30-mile corridor, a set of guidelines had to be utilized to insure consistent and reasonable results. ADT (average daily traffic) model output forecast had to be refined, and then peak hour forecasts developed. The peak hour forecast needed to reflect the effects of peak hour spreading, as well as maintain consistency with forecasts for the surrounding intersections.

This paper outlines the techniques and tools used in the forecasting process, and their application. This paper also presents end results and lessons learned which have proven useful for other project planning studies.

Analyzing the Vehicle Delay Reduction Associated with Constructing Grade-Separated Railroad Crossings

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Abstract. The Hoeven Valley is an industrial area east of downtown Sioux City, Iowa adjacent to an interstate freeway and served by three rail lines. There are few grade-separated rail crossings, resulting in significant delays to east-west vehicle travel into downtown. In an attempt to spur future economic development within the area, a comprehensive look at how to improve the traffic access and operations within and across the area was conducted.

Traffic control at roadway intersections in the form of signs and signals dictates the order in which vehicles can use a shared travel-way. Simulation models are routinely used to analyze these standard intersection types, but can also be used to analyze the vehicle operations near at-grade railroad crossings. A key consideration in developing a travel demand forecast methodology was to represent rail blockage delays on the street system. Several processes were combined in order to evaluate how traffic movements and travel delays would be affected by various transportation strategies such as constructing roadway grade separations and/or street closures. The key component of this methodology was the simulation of at-grade rail crossings by modifying an established traffic simulation model.

The simulation model consisted of trains traveling along rail lines within a roadway network with numerous at-grade crossings. Simulating existing at-grade rail crossings, road closures at the crossings and grade-separated crossings provided estimates for the expected reduction in vehicle delay for a set of roadway alternatives. The vehicle delay reduction and other benefits were then derived for each alternative and compared to the existing condition. The simulation models helped illustrate the operational benefits of grade-separated crossings during public involvement sessions while the model results provided input for benefit-cost analysis, leading to a prioritized list of projects within the Hoeven Valley.

Environmental Impact Study for the Extension of I-69 in Southwest Indiana

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Vincent Bernardin, *Bernardin, Lochmueller & Associates*

Abstract. The Indiana Department of Transportation is nearing completion of a Tier 1 Environmental Impact Study for the extension of Interstate 69 from Indianapolis to Evansville, in Southwest Indiana. This Study has many noteworthy features, including:

- ***Using a Geographic Information System (GIS) to determine transportation-related need and transportation performance of alternatives.*** Using a GIS-based transportation model (TransCAD), the needs analysis for the study identified personal accessibility as a major need. Performance indicators for the alternatives screening included GIS-based accessibility indices for access to population, employment, airports, major universities, and the state capital of Indianapolis.
- ***Using a Regional Economic Simulation Model (REMI) to estimate induced population and employment growth caused by highway alternatives.*** For each highway alternative, monetary user benefits (travel time, vehicle operating, and safety) were input into a 53-industry sector REMI model to forecast added economic growth related to the highway. These forecasts included growth in population and employment. These forecasts were fed back into the travel model, which was rerun for the forecast year (2025) to include these estimates of additional population and employment growth induced by the highway. The transportation performance analysis of alternatives in the DEIS includes this Ainduced@ travel brought on by economic development.
- ***Using a Regional Economic Simulation Model (REMI) to estimate indirect land use impacts.*** With economic growth comes changes in land use, as land is taken from other uses for additional homes and businesses. The forecasts of population and employment growth were used to estimate additional acreage of farmland, forested land, and wetlands which would be taken as indirect impacts of the I-69 project.
- ***Use of GIS to estimate impacts in a Tiered Environmental Study.*** Since this is a Tiered EIS, the Record of Decision will specify only a variable-width corridor (approximately 2000 feet in width) in which a highway would be located. Subsequent Tier 2 NEPA Studies will determine an exact alignment for the highway, and specify mitigation in greater detail. In the Tier 1 EIS, a GIS with more than 170 layers was built for the 26-county study area which included all key layers with environmental information. For the corridor associated with each alternative, a working alignment was specified, which varied in width from 240 feet to 470 feet, depending upon location and terrain. The environmental impacts of each alternative were determined by applying the working alignment for each corridor to the relevant environmental layers in the GIS.

Alternate Approaches to Modeling Work Trip Mode/Destination Choice

John Gibb and Bruce Griesenbeck, *DKS Associates*

Abstract. Historically, nested logit models for mode choice have been implemented with alternatives grouped into nests by mode of travel (i.e. an "auto" nest with drive alone and carpool, a "transit" nest with all transit submodes and access modes, etc.). These groupings are made under the expectation that the "similarity" between alternatives implies correlation of their random utilities. This study tested alternative nesting structures for a work-commute mode choice model, and found particular improvement nesting drive-alone and transit by auto access as an innermost nest, while leaving the carpool alternatives and bicycling ungrouped, leaving them at the level closest to the root. This result suggests the "similarity" between alternatives may be dominated more by traveler situations (need and availability of a car, or a carpool partner, etc.) than by types of vehicles used for travel.

Another common historical assumption is that the coefficients for "in-vehicle time," as a generic variable in mode choice models, is the same for auto travel time and transit in-vehicle time. This study examines auto and transit in-vehicle times separately, and finds auto time's coefficient roughly three times that of transit in-vehicle time.

This study also investigates some alternate treatments to zone size, especially as it affects walk access to transit and directly walking. The conventional assumption that the closest quarter to half mile of zones to transit is "accessible" is reviewed and examined, in a modeling situation where actual "point-to-point" measures are not available and the application is zonal aggregate.

This study endeavored to estimate the weights of transit travel time components by maximizing matches between the modeled transit paths and the respective observed transit paths. Typical "good practice" weights outperformed others, but data limitations prevented further refinement.

Estimation of a destination choice model, nested with mode choice models, is also discussed. The investigation includes use of a non-linear transformation of auto time in the destination choice utilities, to capture effects of trip length not explained by the mode choice inclusive values alone.

Parking Cost, Time-of-Day and Vanpool Models for the Puget Sound Regional Council

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Abstract. Cambridge Systematics is assisting the Puget Sound Regional Council (PSRC) in implementing short-term improvements to the current regional travel forecasting model. The enhancements that are being implemented include: updating trip generation, special generators and external trip tables, refining volume-delay functions, integrating a truck model, and developing parking cost, time-of-day and vanpool models. This paper focuses on *parking cost, time-of-day and vanpool models*, because these improve the PSRC model significantly from a travel behavioral perspective.

The basic objective of the *parking cost model* is to analyze trends in parking costs and employment variables from parking surveys, and develop a modeling tool that will predict parking charges at both current and emerging employment centers. In this model, available parking inventory data on parking supply and costs by facility in the four regional business districts, as well as PSRC's zonal data related to development densities and travel survey data is used to determine parking cost. There are three unique parking cost models for different trip purposes: work trips, university-bound trips and non-work trips. The model runs tested employment density, parking capacity and employment accessibility as independent variables. The model includes a threshold value of employment accessibility that will determine which future employment centers will have parking costs.

The purpose of the *time-of-day choice models* is to produce trips for each of five time periods, by direction. The choice models determine the share of trips that occur in the peak period based on an assessment of congestion, level of service, purpose and socioeconomic or density variables. The 1999 household travel and activity survey and time-period-specific level-of-service skims from the regional model are used to develop these models. The choice models are specified in a multinomial logit framework with ten utility functions corresponding to five time periods, a.m. peak, midday, p.m. peak, evening and night, and two directions (to home and away from home). Some of the key variables that are found to be significant in explaining commuters' choice of time period are home-to-work distance, home-to-work distance squared, household income and size, direction of trip (to work or to home), carpool dummy, delay and employment proximity by auto mode of travel.

In order for vanpools to be represented in the PSRC forecasting process, it is necessary to determine the auto and transit modes from which the vanpoolers shift when new vanpools are provided. This led to the development of a *vanpool 'prior mode' choice model* that is used to determine the shift in modal shares from auto and transit modes to vanpools. We used a vanpool survey database for King County with information on vanpoolers' household and trip characteristics, and commuters' prior modes, i.e., mode of travel of commuters prior to using vanpool mode for model estimation. This behavioral 'prior mode' model is specified in a multinomial logit structure, based on in-vehicle travel time, number of workers, number of vehicles, household income, cost of travel, and accessibility variables.

Introduction

PSRC is updating their regional travel demand forecasting models based on a set of short-term model improvements identified in the *Land Use and Travel Demand Forecasting Models: Recommendations for Integrated Land Use and Travel Models*, prepared by the University of Washington and Cambridge Systematics in 2001. These short-term model improvements were combined with specific planning application needs at the Regional Council to produce a list of model improvements that were combined with a major model calibration and validation effort.

There were three new models developed using survey data as part of this model improvement project: 1) a parking cost model, 2) a time-of-day choice model, and 3) a vanpool model. This paper presents the model form and parameters for these three model components. The other model enhancements that are being implemented include updating trip generation, special generators and external trip tables, refining volume-delay functions, integrating a truck model, and calibrating trip generation, distribution, mode choice, and assignment models.

Parking Cost Models

Parking costs in urban areas vary significantly depending on factors such as the density of development in the areas surrounding the parking facility, and also on the relationship of parking supply and demand. In most parts of any metropolitan region, development density is low and/or parking supply greatly exceeds demand and, as a result, parking is free. Only when thresholds are reached in one or both of these factors are parking charges likely to be put in place. The levels of these charges will be affected by the same factors. Development density affects land values for parking facilities, as well as for other buildings, and the parkers must ultimately pay these values. Higher prices are also needed to clear the ‘market’ for parking spaces when parking demand increases relative to parking supply.

Approach

We integrated the parking cost model into PSRC’s regional travel model system, so that the results can be used in the regional mode choice models. The parking cost model we developed was based on the inventory of parking cost survey conducted by PSRC in April 2002. Only posted parking prices were collected in this survey and the previous surveys. The parking cost model can be used to determine parking charges for any zone that is identified by a policy decision to be available for parking charges. We have also identified a threshold value above which the parking cost model should be applied. So the determination for zones with new parking charges can either be a policy decision or can be determined based on future employment accessibilities. The following parking cost model sources were reviewed to provide further background on parking cost models:

- *Parking Lot Choice Model*¹ – This is a model for predicting parking location in a park-and-ride situation along a high-speed rail line. It predicts the impact on station

¹ Florian, M. and M. Los, *Impact of the Supply of Parking Spaces on Parking Lot Choice*, Transportation Research Part B, Volume 14B, pages 155-163, 1980.

choice due to a change in parking capacity, addition/suppression of stations, and changes in parking fees; and determines the choice of parking lots in order to minimize travel costs.

- *Modeling Parking*² – This model presents a four-level hierarchy of parking models: parking lot model, parking allocation model, parking policy analysis model, and impacts on land use.
- *Denver Parking Cost Model*³ – This model estimates the average daily parking charge of a zone for the trips with destinations at that zone, based on the parking demand and supply within an influence area of the zone. Since the development of the model, parking supply has not tracked with employment, and the resulting parking cost from the model is under-predicting parking charges.⁴
- *NCTCOG Parking Cost Model*⁵ – A linear regression zonal parking cost model estimates average posted parking prices in a Central Business District (CBD) zone as a function of the employment density of the zone itself and those located within 0.2 mile walking distance.

Data

We developed parking cost models using available parking inventory data on parking supply and costs, as well as PSRC’s zonal data related to development densities and travel survey data to determine parking demand. The original parking survey database contained parking information for 2,968 parking lots in the following CBD areas: Seattle, Bellevue, University District, Everett, Tacoma, and some ferry terminals. The parking cost model estimations are based on employee parking, paid customer parking, and public parking only. Therefore, residential parking and free customer parking, as well as unknown parking lots, were excluded from the database. After the data was cleaned and geocoded, it left us with 2,046 parking records.

Geographic Information Systems (GIS) analyses were performed to determine the Traffic Analysis Zone (TAZ) for each geocoded parking facility. In the PSRC region, there are 134,704 parking spaces in 79 TAZs. The average hourly and daily parking costs, as well as the parking capacity for each of the 79 TAZs, were calculated, and the TAZ-based parking database is then related to the TAZ-level employment data set.

Parking Cost Models

The objective of the parking cost model is to establish a statistical relationship between zonal parking cost and socioeconomic and land use characteristics. Parking costs in urban areas vary significantly, depending on the parking space supply and demand relationship. The difficulty in estimating parking cost relative to TAZs is often identified as a problem for parking cost models, because parking cost for an individual traveler can

² Young, W., *Handbook of Transport Modeling*, pages 409-420, 2000.

³ Comsis Corporation, *Denver Parking Cost Model*, prepared for the Denver Regional Council of Governments, September 1995.

⁴ Denver Regional Council of Governments, *Request for Proposal for the Denver Regional Travel Model Refresh Project*, December 2001.

⁵ Nourzad, F., *Northeast Corridor MIS: 1990 and 2010 CBD Parking Costs*, submitted to NCTCOG, Dallas, Texas, November 1994.

be associated with a zone that is different from the traveler's destination if the parker has chosen to park further away, pay less, and walk to his/her destination. In this parking cost model, the tradeoffs between paying less and walking farther distances to the final destination are seen as a proxy for the parking cost in the destination zone. So the model is applied to the parking cost for a traveler whose destination is in that zone, even if he/she parks further away to pay less, but must walk farther, because this tradeoff in time and cost is captured by the parking cost in the destination zone.

Employment Density

High levels of employment in an area drive high parking demand. Since the size of TAZs varies significantly in the PSRC zonal system, we used employment density (1,000 employees per square mile), instead of the total number of employees as the parking demand factor in the models. The ferry terminals use employment density at the ferry destination terminal rather than the ferry origin terminal, since it is this destination employment that is driving the parking cost at ferry terminals. It is expected that the zonal employment density is a positive determinant for parking cost. Accessibility also plays an important role in determining parking demand. Due to the fact that a parker may not necessarily park in his or her Attraction TAZ, the total employment accessible within 10-minute walking distance was calculated (i.e., 0.5 mile away from the TAZ centroid, assuming a walking speed of 3 mph). Higher accessibility to adjacent employment centers also indicates a higher demand for parking space.

Parking Level Thresholds

In most parts of any metropolitan region, development density is low and/or parking supply greatly exceeds demand, and as a result, parking is free. Only when thresholds are reached in one or both of these factors are parking charges likely to be put in place. The levels of these charges will be affected by the same factors. Development density affects land values for parking facilities, as well as for other buildings, and the parkers must ultimately pay these values. Higher prices are also needed to clear the 'market' for parking spaces when parking demand increases relative to parking supply. We plotted the frequency distribution of the accessible total employment density for the TAZs, where the linear regression models were developed; and for the rest of TAZs, where there was no parking cost information available. The accessible total employment density for zones with parking cost is much higher than those free of parking charges. The analysis concluded that accessible employment density of 2.0 ($\times 1000$ persons per square miles) is regarded as the threshold.

Parking Capacity Variables

Parking capacity is another important determinant for parking cost. We estimated two parking capacity variables: zonal parking capacity per unit area (square miles), and zonal parking capacity per 1,000 employees in the area.

Parking Cost Model Results

The new mode choice model uses daily parking costs for work trips and hourly costs for non-work trips, so we continue using this assumption for parking costs by trip purpose. We estimated three sets of models: home-based work parking cost model using the daily parking cost as the dependent variable; home-based non-work model using the hourly

parking cost as the dependent variable; and home-based college model as a subset of the home-based work model. For the sake of brevity, the modeling results are presented for the home-based work parking cost model only.

In this model, the dependent variable is the average zonal daily parking cost for all TAZs, including TAZs with ferry terminals, while the independent variables are: zonal total employment density; accessible total employment density; zonal parking capacity per unit area in TAZs; and dummy variable for ferry terminals. All these variables were entered in the initial model estimation as the candidate determinants for parking costs, then using a stepwise linear regression method we retained only the significant variables. The resulting linear regression model has the following form:

*Average daily zonal parking cost = 6.75088 + 0.00003 * zonal parking capacity per sq mile + 0.08301 * accessible total employment density - 3.82337 * dummy for ferry terminals*

This model shows that TAZs with higher parking capacity density tend to charge higher prices for daily parking. The model also shows that accessible total employment density is another positive contributor to high daily parking cost. The dummy variable for ferry terminals is negative, meaning that TAZs with ferry terminals have a lower daily parking cost compared with downtown TAZs. This size of this coefficient is close to the fare cost of the ferry trip, which accounts for the differences in parking costs. The model has an R^2 of 0.83, and all explanatory variables are significant with a confidence level of more than 95 percent.

Time-of-Day Models

Two primary types of models are generally used to estimate peak period travel: 1) peaking factor models and 2) choice models. The use of peaking factor models that produce trips by time period has been common practice for a long time, but these models are not able to evaluate the impacts of different alternatives on trips by time period since the factors are fixed over time. Choice models which use traditional logit choice techniques have been used for time of day components of activity-based models, but this is the first multinomial logit time of day choice model for a trip-base modeling system.⁶ Choice models spread the number of trips that occur in the peak period based on an assessment of congestion, level of service, purpose, and socioeconomic or density variables.

The objective of the time-of-day choice models is to provide sensitivity to traveler's temporal decisions with respect to socio-demographic and trip characteristics. This sensitivity to temporal decision-making is expected to have significant impacts on forecasting results, as peak period travel is more likely to be occurring in saturated conditions. Fixed time period factors provide realistic estimates of peaking

⁶ The Metropolitan Transportation Commission (MTC) in San Francisco has developed a binomial logit departure time choice model for the a.m. peak period in their trip-based modeling system.

characteristics under current conditions, but are not sensitive to changes in travel behavior as congestion increases or demographics shift. Using fixed time period factors in the future often results in excessive peak period volumes.

The time-of-day choice models are applied to produce probabilities that trips will occur in one of the five time periods. These probabilities are applied to daily trip tables to produce trip tables by time period and purpose. This process is very similar to how mode choice models are estimated and applied. The sum of the resulting time period trip tables will equal the total daily trips.

Approach

Four time-of-day choice models from San Francisco Bay Area, San Francisco County, Edmonton (Canada), and Dallas-Fort Worth were reviewed for the development of the time-of-day choice models for PSRC.

Time Periods

The most significant difference in the types of time-of-day models is the incorporation of congestion and other factors that affect a traveler's decision to travel either during, before, or after the peak period. Because the peaking factor models are not able to incorporate congestion, these models do not divert trips outside the peak period when congestion increases. We estimated a time-of-day choice model from the 1999 household travel survey that allocates trips into each of the five time periods:

1. A.M. peak from 6:00 a.m. to 9:00 a.m.;
2. Mid-day from 9:00 a.m. to 3:00 p.m.;
3. P.M. peak from 3:00 p.m. to 6:00 p.m.;
4. Evening from 6:00 p.m. to 10:00 p.m.; and
5. Night from 10:00 p.m. to 6:00 a.m.

PSRC staff has identified the time periods and developed the initial peaking factors for the five time periods and highway skims to report travel times for each of the five time periods. These travel times are inputs to the time-of-day choice model. Trips are identified as traveling in a particular time period based on the mid-point time of the trip.

Sequencing

There was also consideration of the placement of the time-of-day choice model within the four-step planning process and, while there may be advantages to moving the time-of-day choice model to an earlier stage in the process, PSRC recommended keeping the time-of-day choice model after the mode choice model as in the current practice at PSRC. This recommendation is based primarily on the fact that the new trip generation and trip distribution models will not be re-estimated by time period, so we would not achieve as much benefit in the model accuracy by moving the time-of-day choice model to an earlier stage in the process.

Modes

The time-of-day choice model was estimated using passenger auto trips only; and the transit assignment process will continue to apply fixed time-of-day factors for the a.m. peak, as is the current practice. The estimation of the time-of-day choice models do not

differentiate between drive alone and carpool modes, but the application of these models allow us to apply the models separately and adjust constants for drive alone and carpool modes individually.

Data

The time-of-day models were estimated based on the 1999 household travel and activity survey conducted by PSRC. The survey database consists of 5,837 households with socioeconomic data and 122,981 records of trips and activities in the year 1999 in the Puget Sound region. For estimation purposes, level-of-service skims from travel demand models, employment accessibility used in the vehicle-availability model and bridge flags (dummy variable) are attached to the survey database.

Time-of-Day Choice Model Development

The time-of-day choice model uses the multinomial logit formulation, a model structure widely used in urban travel demand analysis estimating the probabilities of a decision-maker's choice of travel modes, but currently not very widely used in determining a decision-maker's choice among time periods. In a multinomial logit mode choice setting, the choice among time periods is determined by the following factors:

- Characteristics of the trip maker (e.g., income, age, household size, auto availability)
- Characteristics of travel during a specific time period (e.g., congestion, cost of travel)
- Characteristics of the trip itself (e.g., work versus non-work trips).

The time-of-day models are estimated as choice models with a large and comprehensive database. The models are developed in this multinomial logit framework for eight home-based trip purpose and direction combinations: 1) home to work, 2) work to home, 3) home to shop, 4) shop to home, 5) home to other, 6) other to home, 7) home to school, and 8) school to home. Only the home to work and work to home trip purposes are reported in this paper.

All the variables that were tested and either retained or excluded in the utility equation for the logit choice models was based on their significance and whether the sign of the coefficient was logical. Variables that were tested but not included in the final models included: age, number of vehicles per household, hours worked, and accessible employment by transit or walk modes. A description of the variables retained in the final models and the impact of these variables on the home-based work utility equations are as follows:

- *Travel distance and travel distance-squared* – The distance variables are extracted from the travel demand model skims. The distance coefficients are strongly significant for trips to work, but not significant for work trips to home. The negative sign and large magnitude of the coefficient for the distance variable implies that longer trips to work are less likely in all time periods, but the positive sign on the distance-squared term results in very short and very long trips having a higher likelihood than other length trips.
- *Household income* – The positive sign for the income coefficient specific to a.m. peak period and the negative sign specific to the p.m. peak period for the 'home to work' model indicates that commuters from higher income households are more

likely to travel during the a.m. peak period and less likely to travel during the p.m. peak period than other time periods. This result is further corroborated in the ‘trip to home’ model where the income coefficient for the a.m. period is negative suggesting that commute trips from higher income households are not as likely to be destined to home during the morning peak period. The income coefficients for the p.m. and evening time periods are greater than for other time periods in the ‘trip to home’ model, indicating that higher income commuters are more likely to return home during the p.m. peak or evening time periods. It may be that lower income jobs have more irregular hours than high income jobs and are more likely to occur in off-peak time periods.

- *Household size* – Larger households are more likely to travel to work in p.m. peak than smaller households, as indicated by the positive and significant household size coefficient in the ‘home to work’ model. It may be that larger household sizes indicate the presence of children or more complicated household structures, which, combined with multiple workers in the household, lead to flexible or extended work schedules resulting in more reverse direction work trips. By contrast, smaller households are more likely to travel to work in the a.m. peak period and to return home from work in the p.m. peak and evening time periods, as indicated by the negative and significant coefficients in this model. It is possible that smaller households have fewer outside constraints on work hours and schedules, and work trips can occur in more traditional work hours.
- *Total employment by auto within six miles at Attraction TAZ* – This coefficient is positive and significant for the ‘home to work’ model, indicating that trip to work located in denser urban areas are more likely to occur in all time periods than work trips located in more suburban or rural areas.
- *Carpool dummy* – If a work to home trip is made using the carpool mode of travel, then this variable is equal to one for the mid-day and evening alternatives; otherwise, it equals zero. Carpool trips in the mid-day and evening time periods were combined into an off-peak time period, because they were similar in size and sign when tested separately. Dummy variables for carpool trips in the a.m. and p.m. peak periods were tested separately and as a combined variable. The coefficient of this variable is not significant in the ‘trip to work’ model, but is very significant in ‘trip to home’ model. This coefficient is negative for the off-peak periods, indicating that carpool trips from work to home are less likely to occur in off-peak periods than in peak conditions. It is hypothesized that there are fewer opportunities for casual carpooling from work to home in the off-peak periods than there are from home to work, and that this may be contributing to this variable being significant in the ‘work to home’ model.
- *Congestion level* – The level of congestion or delay is measured by the difference in congested and free-flow times. This variable is found to be negative and significant in both the ‘home to work’ and ‘work to home’ models, indicating that delay affects travel decisions by time-of-day choice significantly. The size of the coefficient in the ‘home to work’ model is more negative than in the ‘work to home’ model, indicating a stronger negative effect on travel decisions for trips from home to work during the congested periods.
- *Bridge dummy* – If a trip is made using one of three bridges in the Puget Sound region (namely Tacoma Narrows, I-90, and SR 520), then this variable is equal to

one; and, if not, it is zero. Bridge trips in the midday and evening time periods were combined into an off-peak time period, whereas bridge trips in the a.m. and p.m. peak periods were tested separately and as a combined variable. This coefficient was tested in both models and was insignificant in the ‘work to home’ model. In the ‘home to work’ model, this coefficient was significant and positive for all time periods, except at night, indicating that there is a higher likelihood that trips across the bridge will be made during daytime hours. These coefficients also indicated that the a.m. and p.m. peak periods would have a higher likelihood of trips across bridges than off-peak periods, which is counter-intuitive to expectations that the bridges are choke points during peak periods. As a result, these variables were not included in the final models.

The model statistics demonstrate that the rho-squared with respect to zero is reasonable (0.27 for work to home and 0.34 for home to work), but the rho-squared with respect to the constants (0.02 for work to home and home to work) shows that the constants account for nearly all the variation in time-of-day choices. While it may be desirable for the variables in the models to account for more of the time-of-day choices, the primary objective of the model is to provide sensitivity to trip characteristics, which is achieved by these models.

Vanpool Models

Vanpooling provides an effective way for commuters in the PSRC region to reduce both travel times and travel costs, compared to other private auto travel modes. As a result, vanpooling usage levels depend most heavily on the numbers of vanpools provided by sponsoring agencies, rather than on the time and cost tradeoffs typical for transit and other private auto modes. Thus, the demand for vanpooling in the PSRC region can be determined quite accurately as equal to the supply of vanpools specified by areas of work trip productions and attractions. However, in order for vanpools to be completely represented in the PSRC forecasting process, it is necessary to determine the auto and transit modes from which the vanpoolers shift when new vanpools are provided. The information collected by vanpool providers on the users of their services is expected to provide the basis for a better means of predicting the ‘former modes’ of these users.

We obtained data on the vanpool users from the PSRC, including traveler, household and trip characteristics, and the prior mode(s) used for commuting (these data were geocoded to PSRC TAZ). Based on these data, we estimated prior travel modes using a behavioral ‘former mode’ model for person trips with the purpose of to or from work. Since all vanpools operate only in the peak periods, the vanpooler ‘former mode’ model is inherently a peak period model.

We reviewed several of the following existing vanpooling study reports to evaluate their usefulness for the development of this vanpooling model:

- The Vanpool Study⁷ was designed to assess the current vanpool market and recommend future growth opportunities for vanpooling in the Puget Sound region.
- Vanpooling data collected by Metro, Pierce Transit, and Community Transit agencies have been geocoded to TAZs (work end) and zip codes (home end) for use in this study.
- Kitsap Transit has a worker/driver program, where the agency owns and maintains older buses for the purposes of providing ridesharing opportunities for residents.
- A vanpooling model from Chicago (Illinois)⁸ was reviewed for variables impacting vanpooling mode choice. This model provides information about the effect on vanpool propensity of differences in the proposed services based on stated-preference survey data.

Approach

Vanpool models were estimated using the ALOGIT software for home-based work trips. The vanpool model is multinomial in form and predicts the share of vanpool trips that are from one of six former modes: drive alone, carpool, vanpool, bike, walk, and bus. There is also a seventh choice that identifies vanpoolers who were not commuting prior to taking a vanpool.

Data

Vanpool Travel Behavior Survey

The vanpool model was estimated based on a vanpool survey database for King County that has information on commuters' prior modes (i.e., mode of travel of commuters prior to using vanpool mode). In addition, the database consists of sociodemographic information, such as vehicle ownership, household size and income, O-D information, vanpool fares, and information on whether the commuter has changed work and/or home location. For estimation purposes, commuters who have changed work and/or home location are not included in order to focus on only those commuters who have switched from their prior mode to the vanpool mode, while living and working in the same home and workplace, respectively. The LOS variables like travel time and cost are derived from the a.m. peak period travel demand model, as all of the vanpool trips are work related and take place in the a.m. and p.m. peak periods. In addition to LOS variables, employment accessibility variables are derived from the vehicle-ownership model and are attached to the estimation data based on O-D TAZ information.

Inventory of Vanpool Demand

The vanpool model identifies vanpool demand based on the inventory of vanpool services provided by vanpool surveys conducted in each of the four counties. It is assumed that all operating vanpools are filled to capacity. The vanpool inventory in King County was

⁷ Washington State DOT, *Puget Sound Regional Vanpool Market Study*, Executive Summary, October 2000.

⁸ Koppelman, F. S., J. L. Schofer, C. R. Bhat, and R. Gremley, *Market Research Evaluation of Actions to Reduce Suburban Traffic Congestion: Commuter Travel Behavior and Response to Demand Reduction Actions, Final Report - Part II*, prepared for the U.S. DOT, Report Number IL-11-0033.

based directly on users; and in all other counties, the vanpool inventory was based on vans, so an estimation of vanpool users based on average passengers per van was used to convert vans to vanpool users. The vanpool ridership averages are computed from the individual county vanpool databases.

Vanpool Model Development

In all, seven prior mode options are identified and estimated in a multinomial logit framework. The following variables were tested, but not included in the final model primarily because these were not statistically significant: in-vehicle travel time, vanpool fare, household income, trip distance, and employment accessibility. The following are variables that were specified in the final model:

- *Operating cost* – This variable, only defined for the drive alone former mode, is calculated as distance times cost per mile at \$0.12 a mile. The coefficient is found to be negative and significant indicating that when drive alone operating costs are high, the propensity for the vanpool user to have switched from drive alone to vanpool is lower than the propensity to have switched from any of the alternative modes. On the other hand, when drive alone operating costs are low, the former mode is more likely to be drive alone.
- *Employment accessibility by transit* – The number of jobs within 30 minutes by transit mode from the trip destination TAZ is specified as a set of variables for the drive alone, carpool, vanpool, and bus modes. As expected, the bus coefficient is positive, while negative for each of the other modes, indicating that commuters who shift to vanpool are more likely to have used bus when their workplace is accessible by transit.
- *Number of workers per household* – The negative and significant coefficients for each of the motorized modes indicate an overall negative effect on the choice of any of these modes, rather than either walk or bike when there are more workers in a household. This could be attributed to different work schedules and locations among household members, and limitations in the number of vehicles per household available for work trips.
- *Number of vehicles per household* – Relative to the bus mode of travel, these coefficients are more positive for drive alone, carpool, and vanpool, reflecting the obvious choice of auto modes of travel by workers in households with higher vehicle ownership.

The rho-squared with respect to zero is 0.37 and the final log likelihood is -1,524. The model coefficients are reasonable and the statistics indicate a reasonable fit with the data.

Vanpool Model Integration

The vanpool model was integrated into the PSRC travel demand process after the home-based work mode choice model, because it is assumed that all vanpool trips are work trips. The model estimates shares of prior modes that are applied to the home-based work trip tables to produce person trip tables for seven modes, namely drive alone, auto access to park-and-ride lots, share ride two persons, share ride 3+ persons, walk access to transit, bike, and walk. The trip tables created from the vanpool ‘prior mode’ model are then deducted from the work mode split person trip tables. Following the creation of the modal trip tables, vanpool trip tables are assigned to the HOV network, along with

carpool and drive alone trip tables in a multi-class assignment to produce traffic volumes for highway facilities

Summary

This paper demonstrates the estimation and implementation of parking cost models, time-of-day choice models, and vanpool 'prior mode' models within the four-step travel forecasting process of PSRC. As a result, it improves the performance of the travel demand model to a significant extent that it can now capture the behavioral mechanisms and decision making process of commuters when subjected to different parking prices, congestion levels, and alternative modes of travel like vanpool services. The average zonal parking cost was found to be dependent on zonal parking capacity per square mile, accessible total employment density, and existence of ferry terminals. The model showed that the daily parking prices mostly depends on the parking capacity density. The time-of-day choice models showed that they distribute the number of trips that occur in the peak period over to adjacent time periods based on an assessment of congestion, LOS, purpose, and socioeconomic or density variables. Finally, the vanpool 'prior mode' model enabled the modeling process to deduct the appropriate number of trips from non-vanpool modes so that the vanpool trips can be captured accurately.

Forecasting Traffic for an HOV Lane from Feasibility Study to Preliminary Design

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Andrew Stryker, *Parsons, Brinckerhoff*; and Cathy Chang, *PBConsult Inc.*

Abstract. A feasibility study for adding an HOV lane to the western portion of the Eisenhower Expressway (I-290) in the Chicago metropolitan area was completed in 1998. This feasibility study concluded that the HOV lane was a viable means of reducing travel times and increasing the movement of persons in the corridor. The proposal has since moved forward as part of the reconstruction of the Eisenhower Expressway, which is currently in the preliminary design stage. The original feasibility study included base and future 2010 traffic forecasts for the Eisenhower general purpose and HOV lanes and comparable traffic forecasts have recently been completed for the Eisenhower reconstruction. These new forecasts serve two general purposes; first, to confirm the findings of the feasibility study in light of a new regional plan, substantially updated forecasts of future population, households and employment, and a ten year later 2020 design year, and second; to provide traffic data for signalization, intersection and weaving section studies.

The paper compares the modeling procedures followed to forecast traffic in the feasibility study and in the preliminary design studies, noting enhancements made possible by software and hardware improvements. It also describes how the revised socioeconomic forecast and more distant design year affect the estimated future time savings and usage of the HOV lane. Modifications to modeling procedures and adjustments in network coding that were carried out to supply supporting traffic estimates for design purposes are also discussed. The overall theme of the paper is how modeling procedures have to adapt during a lengthy, somewhat repetitive facility planning process that shifts its focus from evaluation to design.

A feasibility study of a proposed HOV facility in a major radial expressway corridor in northeastern Illinois was completed in 1998 (1). It concluded that the addition of an HOV lane was a viable means of reducing travel times and increasing the person flow in the corridor. Based on these findings, the HOV lane was later included in the region's 2020 regional transportation plan. More recently, preliminary engineering and environmental studies were initiated for reconstruction of the expressway with the proposed HOV lane.

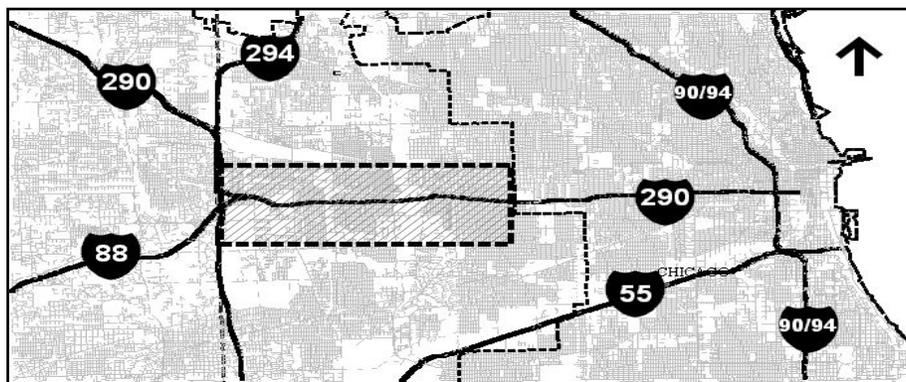
The original feasibility study included 2010 traffic forecasts for the expressway's general purpose lanes, HOV lane, and adjacent arterial streets in the expressway corridor. These forecasts were redone for the preliminary engineering and environmental studies with a 2020 design year. Despite the relatively short period of time between these two studies, there are significant differences in the modeling methodology, demographic and employment forecasts, highway network, and regional plan underlying the traffic projections. The two studies also have a different focus. The feasibility study forecasts were the basis for a planning level evaluation of the HOV facility, and also helped resolve some basic design issues for the HOV facility. Traffic forecasts for the reconstruction of the Eisenhower substantiated the general findings of the feasibility study and provided detailed traffic estimates for design purposes.

The following sections summarize the major differences between the traffic forecasts for the two studies. Although both studies employed generally the same set of Chicago Area Transportation Study (CATS) models, there are methodological differences between the two modeling efforts due to software and computing advances that allow more nearly equilibrium modeling of trip distribution and assignment. Differences in methodology are also caused by the need for detailed traffic estimates in the expressway reconstruction studies. Observed differences in the two studies' traffic projections can be traced to changes in forecasted model inputs or highway improvements completed since the feasibility study that have increased expressway and parallel street capacities in the western part of the corridor.

Scope of the Studies

The 1998 study examined the feasibility of an HOV facility in an eight mile corridor along the Eisenhower Expressway (FAI-290) in northeastern Illinois. This corridor runs roughly from the Chicago city limits on the east to the Cook-DuPage county line on the west where the Eisenhower and I-290 Extension interchange with the TriState Tollway (FAI-294) and East-West Tollway (FAI-88). The location of the feasibility study corridor is shown in Figure 1.

FIGURE 1 FAI-290 HOV Lane Corridor



Two levels of evaluation were completed in the feasibility study. At the regional planning level, the feasibility study examined how the HOV lane affects transit ridership and traffic on other major highway facilities, and whether it causes an increase or decrease in regional vehicle-miles and emissions. A second project level evaluation in the feasibility study analyzed the general design and operation of the HOV facility, including the question of minimum vehicle occupancy requirements. Should vehicles with two persons ridesharing be allowed to use the HOV lane, or should its use be restricted to vehicles with three or more persons carpooling? Since the vehicle occupancy requirement affects HOV traffic, two sets of forecasts were typically prepared for the two minimum vehicle occupancy requirements.

Several different designs were considered for the HOV facility in the feasibility study, ranging from a shoulder HOV lane separated from general purpose lanes by pavement striping to a newly constructed HOV facility with a barrier between the HOV lane and adjacent general purpose lane. Traffic forecasts were prepared for these two alternate designs, primarily to analyze how the amount of access to the HOV facility affected estimated traffic and weaving distance requirements for movements between the HOV lane and general purpose lanes.

Traffic forecasts for the Eisenhower Expressway reconstruction studies dealt only with a single HOV lane facility, the design recommended by the feasibility study. This is a barrier separated HOV lane with very limited access from the general purpose lanes to the HOV lane. Vehicles can only enter the HOV lane at the beginning of the lane and at a location roughly midway in the corridor. The project limits closely match the east and west limits of the corridor used in the feasibility study. The reconstruction of the Eisenhower Expressway extends eastward into the City of Chicago, but the eastern terminus of the HOV lane is at approximately the same location as in the feasibility study.

The initial work element of the expressway reconstruction traffic forecasting was to reexamine the findings of the feasibility study. Although there were minor differences between the new traffic projections and the feasibility study forecasts, the findings and conclusions in the feasibility study were generally substantiated. Additional model runs were then prepared to: (1) compute the travel time savings and other benefits of the HOV facility; (2) complete an independent validation of the models by comparing model results with existing corridor traffic conditions and vehicle occupancy levels, and (3) provide more detailed estimates of traffic movements at interchanges, ramp junctions and weaving sections required for the continuing preliminary design. These traffic forecasts again considered alternate vehicle occupancy requirements in order to use the facility.

Model Inputs

Both sets of traffic forecasts were developed with the CATS regional travel demand models and analysis zones. At the time of the feasibility study, these zones covered eight counties in Illinois and one in Indiana as shown in the left-hand side of Figure 2. The CATS zone system was later enlarged to include the additional counties in the right-hand side of Figure 2.

The regional 2020 demographic and employment forecasts for the Eisenhower Expressway reconstruction traffic estimates take into account population, household, and employment growth between the 2010 forecast year for the feasibility study and the more distant 2020 forecast year. In addition, these regional socioeconomic forecasts were revised after the feasibility study was completed, which changed the regional allocation of population, households, and employment. A further complication is that the 2020 regional plan considers multiple development scenarios to account for a third regional airport located in the south suburbs. The socioeconomic forecasts used for the expressway reconstruction 2020 traffic projections are based on the future development scenario that includes major planned investments in the O'Hare airport complex without a third regional airport in the south suburbs.

FIGURE 2 Regional Zone Systems Used in the Two Studies

a. Feasibility Study Traffic Forecasts

b. Preliminary Engineering Traffic Forecasts

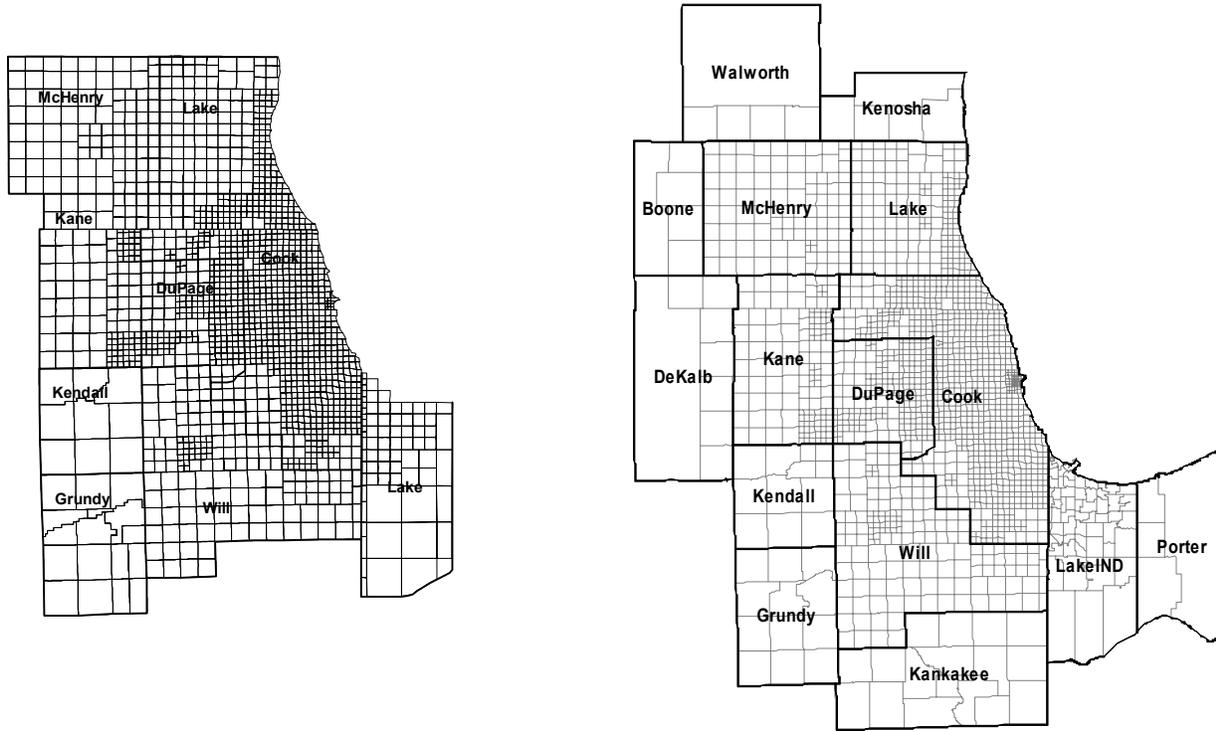


Table 1 - Person Trips in the HOV Studies

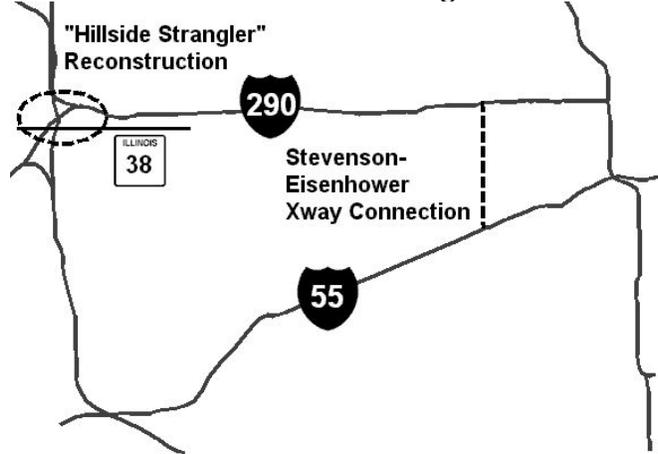
Trip Purpose	Forecast Year		% Change
	2010	2020	
Home-Based Work	5,136,092	8,657,626	69%
Home-Based Other	8,291,757	13,849,488	67%
Non-Home Based	4,765,306	8,338,653	75%
Total	18,193,155	30,845,767	70%

Table 1 summarizes the 2010 and 2020 regional person trip tables for the two traffic forecasts. The 2020 forecast has roughly two-thirds more home-based work person trips than the 2010 forecast, the principal type of trip expected

to use the HOV lane during the peak periods. Even though the 2020 study area is somewhat larger than the 2010 study area (compared in Figure 2), the growth in trips is still substantial.

The 2020 Regional Transportation Plan (RTP) for northeastern Illinois (ⁱⁱ) updated the 2010 plan in effect at the time of the feasibility study. Changes in the plan affect future traffic in the Eisenhower HOV lane corridor since the networks used to model future traffic include all major highways in the regional plan. The difference between the 2010 and 2020 plans that is most relevant to the HOV lane traffic forecasts is a short section of north-south expressway proposed to link the Eisenhower (FAI-290) and Stevenson (FAI-55) expressways. This project was included in the 2010 plan but eliminated from the 2020 plan.

Figure 3 - The 2010 Plan Connection Between I-290 and I-55 and “Hillside Strangler”



The location of the deleted expressway connection between the Stevenson and Eisenhower expressways is shown in Figure 3. It is approximately four and one-half miles east of the eastern end of the HOV lane.

Shortly after the feasibility study was completed, a short portion of the Eisenhower Expressway at the far western end of the corridor was reconstructed. This reconstruction added capacity to reduce a bottleneck (locally known as the “Hillside Strangler”) for eastbound traffic entering the Eisenhower from the East-West Tollway (FAI-88), Roosevelt Road (Illinois

38) and the I-290 Extension. The original feasibility study forecasts of eastbound traffic on the HOV lane reflect the previous bottleneck conditions.

Finally, the currently recommended design for reconstruction of this portion of the Eisenhower Expressway has some changes that affect the network coding in the corridor. Some interchanges are eliminated and several interchanges are combined. Ramp geometrics are also changed at a number of interchange locations.

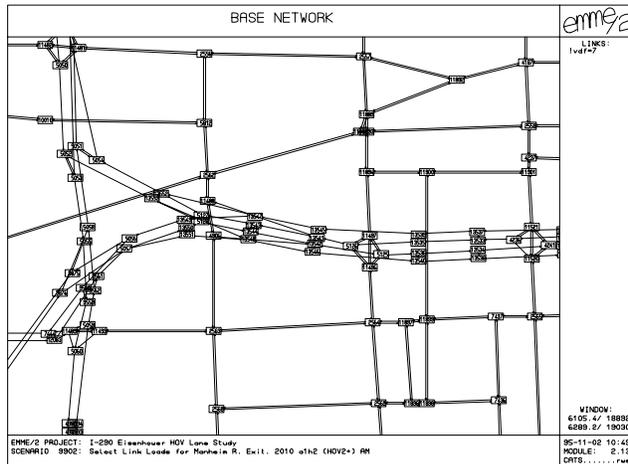
To summarize, the highway networks for modeling future traffic in the Eisenhower Expressway reconstruction studies start with the CATS 2020 plan highway network. The Eisenhower Expressway corridor portion of the networks are then recoded for the reconfigured interchanges, “Hillside Strangler” reconstruction, and recommended HOV lane alternative, which features limited access from the general purpose lanes.

Traffic Forecasting Methodology

The methodology of the feasibility study traffic forecasts consists of AM and PM peak hour multi-vehicle class equilibrium highway assignments carried out using the EMME/2⁽ⁱⁱⁱ⁾ travel demand modeling software iterated with an enhanced version of the CATS mode choice model. The most recent documentation of the CATS models can be found in appendices to the northeastern Illinois air quality conformity evaluation^(iv) documents.

Drive alone, two persons sharing a ride, three or more person carpool and transit person trips are predicted by the feasibility study's mode choice model. The three auto sub-mode person trip

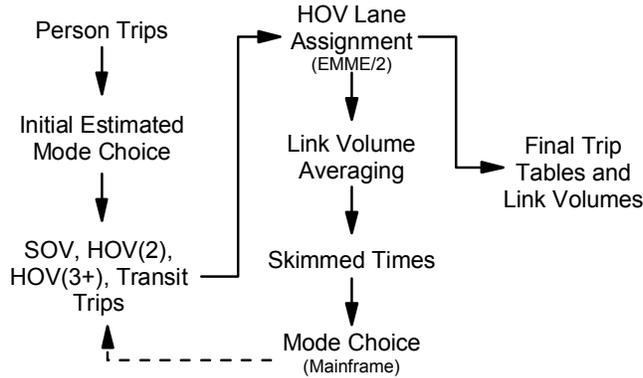
Figure 4 - HOV Lane Coding



tables by vehicle occupancy level are then factored to vehicle trips and assigned to the highway network. The assignment procedure is a multi-vehicle class procedure that requires network coding to identify the vehicle classes that can use links. The HOV lane links are coded so that both two person and three or more person vehicle trips are assigned to the HOV lane when the minimum occupancy requirement is two persons, or alternately, only the three or more person vehicle trip table is assigned when the minimum occupancy is three or more persons. The coding of the western end of the HOV lane in the feasibility study is shown in Figure 4.

The mode choice model used for the feasibility study extended the CATS model to include the auto occupancy level sub-mode choices. It combines CATS original transit-auto binary choice model with the auto sub-mode portion of the mode choice model developed for the Maryland National Capital Parks and Planning Commission (^v, ^{vi}, ^{vii}). Iterating between assignment and mode choice allowed the equilibrium between the transit and auto sub-mode shares and the travel conditions faced by users of the four modes to be estimated. Network coding and link volume delay functions are used to reproduce alternative designs for the HOV facility and the bottleneck traffic conditions that exist in the Eisenhower corridor. Figure 5 shows the overall sequence of models applied in the feasibility study. The dashed line indicates the feedback loop from mode choice to traffic assignment. In the feasibility study, the models were iterated through this loop three or four times depending on whether the base network or a network containing an HOV lane alternative was modeled. At the time, this iterative procedure was extremely cumbersome since EMME/2 and the mode choice model were run on different computing platforms. Note that the feedback did not go back to distribution and the person trip table is fixed through all iterations of the mode choice and assignment models.

Figure 5 - Feasibility Study Modeling Steps



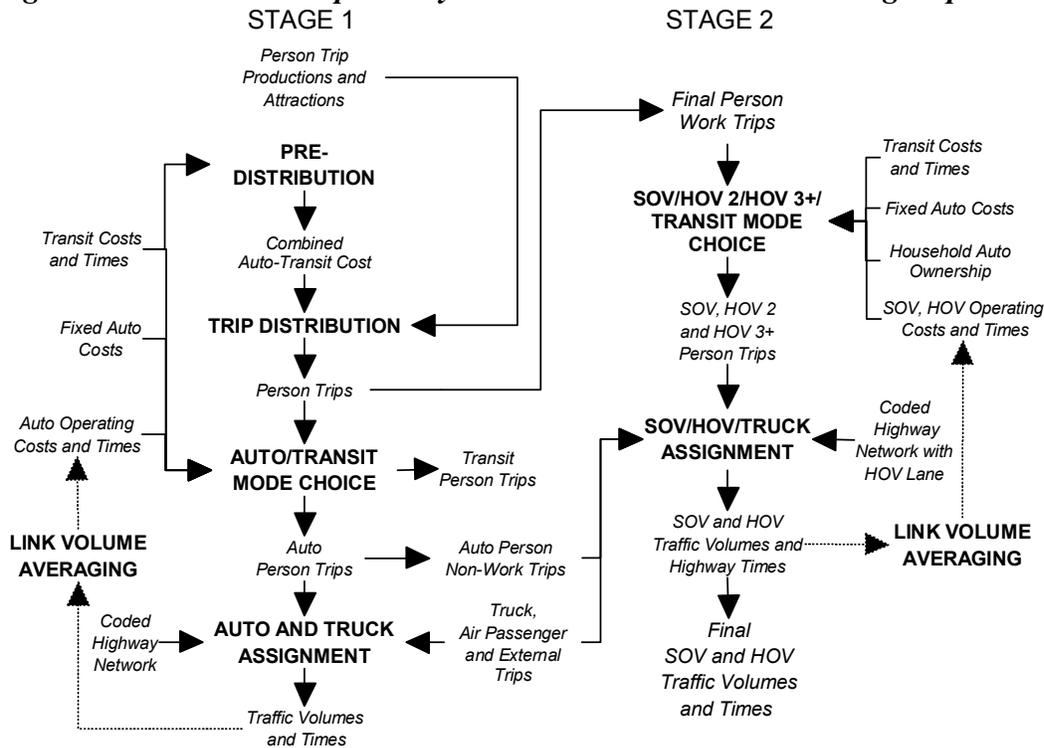
The traffic forecasts for the Eisenhower Expressway reconstruction were prepared with the models originally developed by CATS for the feasibility study. Morning and evening peak period traffic forecasts were completed following the procedures established for the feasibility study with a few enhancements made possible by hardware improvements and advancements in more recent versions of the EMME/2 transportation modeling software (^{viii}). All of the computing was done on personal computers. How the models are employed in the expressway reconstruction studies is

illustrated by the flow diagram in Figure 6, which is more complex than the feasibility study model steps in Figure 5.

The first stage on the left consists of the model steps required to estimate person trips between zones. The final person trip table for work trips from Stage 1 is then subjected to a second stage of modeling that splits them into transit and auto person work trips by single occupancy vehicles (SOV), two persons sharing a ride (HOV 2), and three or more persons carpooling (HOV 3+). In the remainder of Stage 2, the three auto occupancy levels are collapsed and factored into an SOV and an HOV vehicle trip table and assigned to a highway network containing links representing the HOV lane.

There are implicit assumptions in this two stage modeling process. The Stage 1 model steps that produce the person work trip table depend on the characteristics of auto travel without regard to vehicle occupancy, while Stage 2 modeling of mode and vehicle occupancy choices assumes a fixed person trip table. In behavioral terms, choice of a destination workplace is assumed to depend on general auto accessibility, while the decision to ride share or carpool is only made after the workplace is determined. Another assumption is that only work trips' vehicle occupancy levels are influenced by the possible time savings from use of the HOV lane. This assumption is required because the portion of feasibility study mode choice model that determines vehicle occupancy was only calibrated for work trips. Therefore, only work trips go through the second stage mode and vehicle occupancy choice modeling, while non-work trips are factored to two and three or more person vehicle occupancy trip tables based on observed non-work auto occupancies.

Figure 6 - Eisenhower Expressway Reconstruction Studies Modeling Steps



After comparing the expressway reconstruction traffic forecasts against those from the feasibility study, a series of additional detailed traffic forecasts were completed to provide inputs for microsimulation of traffic behavior in weaving sections, ramp junctions and signalized intersections. Changes in model inputs required for these design oriented traffic forecasts include:

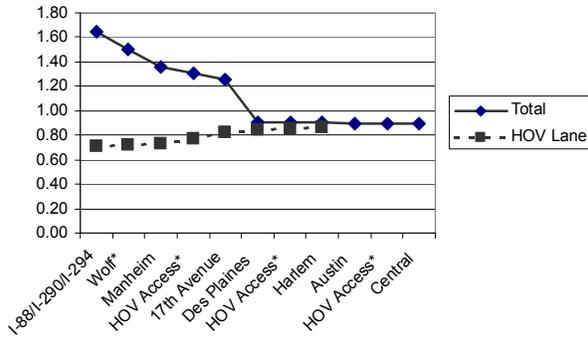
- Coding additional links (expressway frontage roads and adjacent local streets) into the highway network used for the traffic estimates. These links were not part of the feasibility study networks.
- Identifying critical intersections (nodes in the network) for turning movement estimates. Turning movement forecasts were not considered in the feasibility study.
- Testing of alternative modeled relationships between freeway traffic volumes and delays to more accurately reproduce freeway operating conditions when traffic volumes approach capacity.
- Limiting access to the Eisenhower Expressway on ramps with metered control by constraining the traffic volumes on these ramps to reasonable metered flow volumes.

Traffic Forecasts

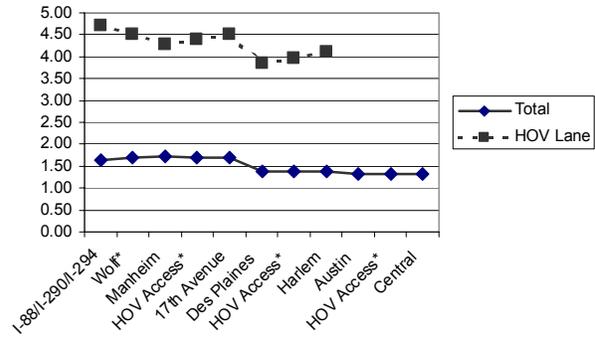
Estimated traffic volumes from the expressway reconstruction traffic forecasts were compared against the original feasibility study traffic estimates. The results of this comparison are summarized in Figure 7 for an HOV lane with a three or more person occupancy requirement.

Figure 7 - Comparison of Feasibility Study and Eisenhower Reconstruction Traffic Volumes with Three or More Person HOV Lane in Place

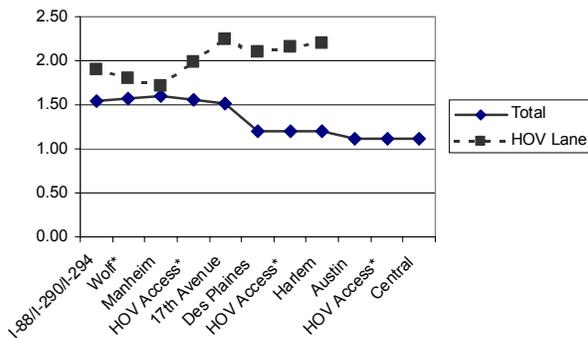
a. AM Peak Period Eastbound



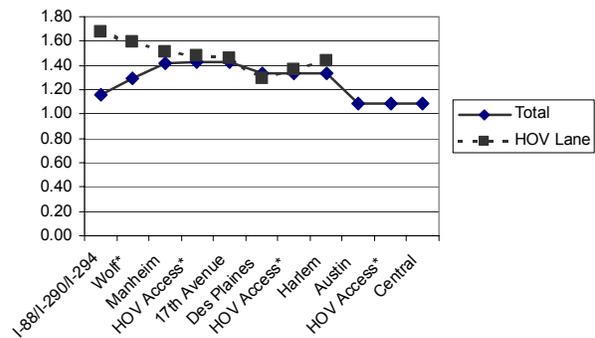
b. AM Peak Period Westbound



c. PM Peak Period Eastbound



d. PM Peak Period Westbound



Four plots are shown in Figure 7 for AM and PM peak period traffic by direction. Each data point is the ratio between the 2020 expressway reconstruction estimated traffic and the 2010 estimates from the feasibility study (the HOV lane design with nearly continuous access) at a series of locations in the corridor. The diamond data points are for combined general purpose and HOV lane traffic; the square data points for HOV lane traffic only. The plots in the upper left and lower right panels correspond to traditional AM inbound and PM outbound commuting direction traffic movements. The upper right and lower left panels are “reverse commute” movements.

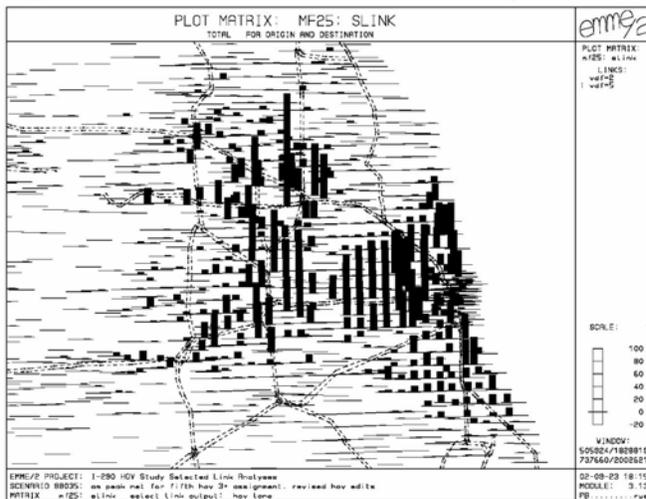
These plots and the not shown two or more person HOV lane plots show how the traffic forecasts have changed since the feasibility study was completed. The following bullet points highlight the most apparent differences.

- **Greater Increase in Reverse Commuting Traffic.** Increased traffic can be observed at nearly every data point in the combined general purpose and HOV lane traffic, but overall traffic growth is more pronounced in the reverse commute directions. These results are consistent with a more dispersed pattern of forecasted development. They also reflect the fact that feasibility study traffic flows in the peak direction were already near capacity and only limited increases are possible.

- Increased Traffic Through the “Hillside Strangler.” Additional traffic at the western end of the corridor reflects the increased capacity in the general purpose lanes after the “Hillside Strangler” improvements.
- HOV Lane Traffic Generally Increases More Than General Purpose Lane Traffic. With the exception of the far western end of the corridor, the HOV lane traffic generally increases more than traffic in the general purpose lanes. This is in spite of the current HOV lane design, which has reduced access compared to the feasibility study.
- Heavy Use of HOV Lane in Reverse Commute Directions. One of the more surprising results in the above two figures is the growth in HOV lane traffic in the reverse commute directions, particularly in the AM peak period.

Forecasted traffic in the reverse commute direction on the HOV lane increased to such an extent that a special “select link” analysis was undertaken to verify the reasons for this additional HOV traffic. The results of this analysis are shown in Figure 8.

Figure 8 - HOV Lane Select Link Analysis



In a “select link” assignment the origins and destinations of all trips passing through one link are tabulated. In this case, the selected link is a westbound HOV lane (three or more person auto occupancy requirement) link in the middle of the corridor. The AM peak period home trip origins and work destinations are depicted in the spatial bar diagram in Figure 8. Locations to the right of the midpoint in the corridor correspond to home trip origins, while locations left of the midpoint match work destinations.

As shown in the figure, most of the HOV home trip origins are from inner city

areas, particularly the near west side. Work destinations are in western Cook County, eastern DuPage and the industrial areas around O’Hare Airport. The conclusion is that increased home-work HOV travel in the reverse commute direction occurs for two reasons. First, there is considerable growth in employment projected for the suburban areas that are west of the HOV lane, in particular the area surrounding O’Hare airport. The growth around O’Hare reflects the fact that the development scenario does not include a third regional airport. The second reason is the additional forecasted population and households for inner city areas east of the HOV lane. These are areas with relatively low vehicle ownership, an important variable in the mode choice model that affects the allocation of trips to higher auto occupancy sub-modes.

Final Comments

In the authors' experience it is unusual to repeat the same facility forecasting process within a span of approximately six to seven years. During this short period, basic inputs to the HOV lane's traffic forecasts were revised to a far greater degree than envisioned at the time of the feasibility study. A major expressway was removed from the regional plan, and new assumptions and trend data led to larger future population and employment forecasts allocated differently across the region. Even without fundamental changes in the models, the model applications in the expressway reconstruction studies are far more complex than in the feasibility study due to software enhancements and computational advances.

During this same period, the utilization of the HOV lane's traffic estimates moved from evaluation to design prompting the methodological changes noted previously. The challenge is how to adapt models and modeling processes to meet these differing purposes while the regional transportation planning environment is continuously changing, often to a far greater degree than anticipated.

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 - ^{iv}. Chicago Area Transportation Study. *Conformity Analysis Documentation, Appendix B*. October, 2000.
 - ^v. Jim Ryan and C.Y. Jeng. *Development of the "New" MNCPPC Nested Logit Model (with HOV Options, New Survey and Skim Data)*. Memorandum to Michael A. Replogle, Director of Transportation Modeling, MNCPPC. COMSIS Corporation, December 15, 1988.
 - ^{vi}. C.Y. Jeng. *Revision of the "New" MNCPPC Nested Logit Model (with HOV Options, New Survey and Skim Data)*. Memorandum to Michael A. Replogle, Director of Transportation Modeling, MNCPPC. COMSIS Corporation, December 16, 1988.
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 - ^{viii}. INRO. *EMME/2 Users Manual, Software Release 9*. Montreal, Quebec, 1998.

Development of a Transit Model Incorporating the Effects of Accessibility and Connectivity

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Fadi Nassar and Wade White, *Gannett Fleming, Inc.*

Abstract. During the past few years, the Public Transit Office of the Florida Department of Transportation has been funding the development of transit demand forecasting models that are easy to use and implement in resource- and staff-constrained environments. Quite often small- to medium-sized transit agencies do not have the resources and staff to implement large-scale travel demand modeling systems or collect and assemble the elaborate databases needed to support such model systems. The model development efforts of the FDOT Public Transit Office have been focused on meeting the transit modeling needs of such agencies and fall within the purview of its broader Transit Model Improvement Program initiative..

Model systems developed under this initiative include the Integrated Transit Demand and Supply Model (ITSUP) presented at the Seventh Conference (1999) in Cambridge, MA and the Regional Transit Feasibility Analysis and Simulation Tool (RTFAST) presented at the Eighth Conference (2001) in Corpus Christi, TX. While those models offered powerful frameworks for modeling transit systems in a user-friendly environment, they did not adequately account for the effects of accessibility and system connectivity on transit patronage.

In order to further enhance the sensitivity of the models to accessibility and system connectivity issues, the authors have developed the next generation of ITSUP and RTFAST. The new model system incorporates specially developed measures of destination (spatial) accessibility, temporal accessibility, and origin-destination connectivity to determine potential ridership on a route. The model system is also sensitive to the presence of transfers and is therefore capable of serving as a powerful route design and route evaluation tool.

The presentation will provide an overview of the new transit model along with a detailed explanation of the accessibility and connectivity measures incorporated into the model. In addition, the presentation will include a demonstration of the capabilities and features of the model system together with calibration and validation results obtained from the Florida-based implementation effort.

A Market Segmentation Approach to Mode Choice and Ferry Ridership Forecasting

Maren L. Outwater, Vamsee Modugula, and Pratyush Bhatia *Cambridge Systematics, Inc.*; and Steve Castleberry, *San Francisco Bay Area Water Transit Authority*

Abstract. The San Francisco Bay Area Water Transit Authority is evaluating expanded ferry service, as required by the California Legislature. Predicting ferry ridership has historically been difficult because water-transit riders often choose their travel mode based on factors other than the travel time and cost. Most forecast models place a premium on time and cost, ignoring other traveler attitudes. As part of this study, Cambridge Systematics developed forecasts using a combination of market research strategies and the addition of non-traditional variables into the mode choice modeling process. We expanded the mode choice model to recognize individual travelers' sensitivity to stress, travel time and environmental factors by segmenting the market.

We used structural equation modeling to simultaneously identify the attitudes of travel behaviors and the causal relationships between traveler's socioeconomic profile and traveler attitudes. We extracted six attitudinal factors, three of which were used to partition the ferry riding market into eight segments. These market segments were used to estimate stated-preference mode choice models for 14 alternative modes, which separated the traveler's reaction to time savings by market segment and recognized that modal choices are different for market segments that are sensitive to travel stress or desire to help the environment.

The new mode choice models were applied within the framework of the Metropolitan Transportation Commission's regional travel model and calibrated to match modal shares, modes of access to each ferry terminal, ridership by purpose, route and time period, and person trips by mode at screenline crossings. Additional validation tests of significant changes in ferry service in recent years were used to confirm the reasonableness of the SP model.

The focus of this paper is on the application of the model to evaluate three future year alternatives and to test the sensitivity of pricing policies, service changes and alternative transit modes. These sensitivity runs included increased tolls on bridges, parking charges for BART stations, reduced ferry headways, alternative transit investments (express buses) in ferry corridors and combinations of these assumptions. The results from these model runs were used to support the environmental impact statement (EIS) and implementation and operations plan (IOP), and were used to prioritize routes for further consideration based on the ridership potential in the corridor. Preliminary work to competitively position a ferry system that maximizes ferry mode share based on the market segments in the corridor was undertaken for a few routes.

The San Francisco Bay Area is one of the most beautiful places on earth, with sweeping views of a bay dotted with waterfront communities. These communities are often set against a backdrop of spectacular hillsides with multi-million dollar homes that face the San Francisco skyline. Many of the elements that make the bay so beautiful also

challenge its transportation network. The eight bridges that cross the bay are often congested with commuters, with the San Francisco Bay Bridge historically being the most congested corridor in the Bay Area.

The traffic bottlenecks caused by these bridges have provided an opportunity for growth of ferry service. Ridership on the Bay Area's ferry services has seen steady growth over the last 12 years. In 1988-1989, the individual ferry services carried approximately 2.5 million passengers per year. By 1999-2000, that number grew to 7.0 million passengers. Much of that growth has been fueled by failures in the land transportation networks. The most publicized of the failures was the Loma Prieta earthquake in 1989, which closed the San Francisco-Oakland Bay Bridge and forced many commuters to find alternative ways across the bay. Within three weeks of the earthquake, a number of new ferry routes had been established to carry commuters into downtown San Francisco. In addition to the earthquake, a number of smaller system breakdowns, including a 1997 BART strike, sent commuters to the ferry system.

However, the most significant breakdown in the land transportation network is probably the growth in day-to-day congestion in the bridge corridors. Since 1995, Bay Area traffic congestion increased 87 percent. The MTC expects that between 1990 and 2020, the average hours per day that vehicles are delayed will increase 249 percent.

In 2000, the State of California, through legislation, created the Bay Area Water Transit Authority (WTA) to further study expansion of ferry service. It was clear that the acceptance of the WTA's results hinge heavily on the credibility of their ridership forecasts. In 2001, the WTA selected Cambridge Systematics to provide ridership forecasts services, based primarily on a unique approach that responds to concerns from previous studies.

This paper summarizes the market segmentation and mode choice models developed to support ridership forecasting and summarizes the results of ridership forecasts for three alternatives and 10 sensitivity tests. Measures of performance and user benefits are presented to provide evaluation measures for each alternative.

Overview of Market Segmentation and Mode Choice Model Development Identifying and Forecasting Traveler Attitudes

Factor analysis was performed to analyze the interrelationships among 30 attitudinal variables collected in the household survey. It involved a statistical procedure that transforms a number of possibly correlated variables into a smaller group of uncorrelated variables called principal components or factors.¹ The objectives of performing factor

¹ Gorsuch, R. L., 1983, *Factor Analysis* (Second Edition), Hillsdale, New Jersey: Lawrence Earlbaum Associates.

analysis were to reduce the number of attitudinal variables (data reduction) and to detect the underlying structural relationships between variables (i.e., structure detection).²

We developed a Structural Equation Model (SEM) in which the six attitudinal factors were related to the 30 attitudinal statements, and ultimately, to available socioeconomic variables. SEM is a modeling technique that enables us to identify the structural attitudes of travel behaviors, and to quantify the causal relationships between travelers' socioeconomic status or demographic profile and travel attitudes. The primary objective of SEM in this study was to improve the statistical reliability of the relationship between the socioeconomic data and the estimation of factors. This process modified the attitudinal variables in each factor in order to improve the forecasting abilities of the model.

Market Segmentation Models

Market segmentation is one of the most important strategic concepts in market research.³ The process of market segmentation involves identifying variations in customer needs and determining how to fulfill these needs.⁴ The attitudinal factors derived from SEM were used as the basis for market segmentation, the core concept of which is to view a market as several segments rather than one homogeneous group. Cluster analysis was used for segmentation. The objective of cluster analysis was to identify unique travel groups for market profiling. It was useful to the extent that people within the same cluster share similar attitudes toward travel behavior, while people in different clusters held different views.⁵

The survey-based market segmentation model was applied to the whole population in the San Francisco Bay Area. Traffic Analysis Zone (TAZ)-level socioeconomic and demographic data for year 1998 were used to calculate the score of each attitudinal factor using the estimated parameters from SEM. The resulting scores of Factor 1 (Desire to help the environment), Factor 2 (Need for timesaving), and Factor 4 (Sensitivity to travel stress) were then used to divide the Bay Area population into eight segments. The model was also used to forecast the market segments of year 2025 using the MTC data.

Mode Choice Models

For comparative purposes, two sets of models were developed: 1) revealed-preference (RP) and 2) SP mode choice models. The RP models were primarily estimated to test the explanatory power of various levels of service (LOS) and socioeconomic variables in

² Sapleton, C. D., 1997, *Basic Concepts and Procedures of Confirmatory Factor Analysis*, Working Paper at Texas A&M University, January.

³ Myers, J. H., 1996, *Segmentation and Positioning for Strategic Marketing Decisions*, American Marketing Association.

⁴ Chaston, I., 1999, *New Market Strategies*, Guilford, United Kingdom: Biddles.

⁵ Thompson, M. E., 1998, *The Science and Art of Market Segmentation Using PROC FASTCLUS*, prepared for publication in PNWSUG's 98 Conference Proceedings.

different purpose-specific models. These models were then used as a reference, while estimating the SP models that could support much more detailed choice alternatives and include the market segments.

Market segment-related LOS and submode-specific constants were estimated to better understand the implications of various market segments on their mode choice behavior. Only one LOS variable, total travel time, is estimated for market segments that are sensitive to travel time. The in-vehicle travel time coefficient for these market segments is the sum of this coefficient and the in-vehicle travel times of the specific mode. It is found that the market segments that are more sensitive to time have a larger and more negative coefficient than the other market segment coefficients.

Summary of Model Development

This project evaluated two methods for identifying and forecasting traveler attitudes (factor analysis with logistic regression and structural equation modeling) and recommended the use of SEM for use in developing market segments. SEM provided significantly better statistical results for correlating available demographic data with traveler factors, and allowed us to forecast market segments to the year 2025 for use in mode choice and ridership forecasting models. The mode choice and ridership forecasting models were calibrated and validated across trip purposes, primary modes, modes of access, routes, time periods, and screenlines. The models were used to evaluate a series of future year alternatives and sensitivity analyses were conducted. All current and future year ridership results were considered reasonable. The project demonstrated that SP models, in combination with attitude and market segmentation data, enhance the accuracy and explanatory nature of the models.

Forecasts of Alternative Scenarios

There are currently four alternatives planned for study in the environmental document. Each alternative consists of a conceptual program of ferry transit services. Together, the alternatives represent a range of investment in service expansion.

- **Alternative 1 – Comprehensive (Water Transit Initiative) Alternative.** This alternative comprises the largest possible conceptual improvement of the Bay Area’s ferry system. It includes all of the routes and services included in Alternative 2, but is not necessarily constrained by operational requirements or development costs.
- **Alternative 2 – Expanded System Alternative.** This alternative includes promising routes that emerged from the Water Transit Initiative and the MTC ferry studies that could potentially be implemented within a 10-year horizon. It also includes expansion of service on existing routes.
- **Alternative 3 – Enhanced Existing Service Alternative.** There are currently six ferry routes serving the Bay Area. This alternative would focus on expansion of this existing system.
- **Future Base – No Project Alternative.** This alternative would involve minimal service improvements. Ferry service would continue to operate on existing routes at about the same frequency, as determined by each service provider.

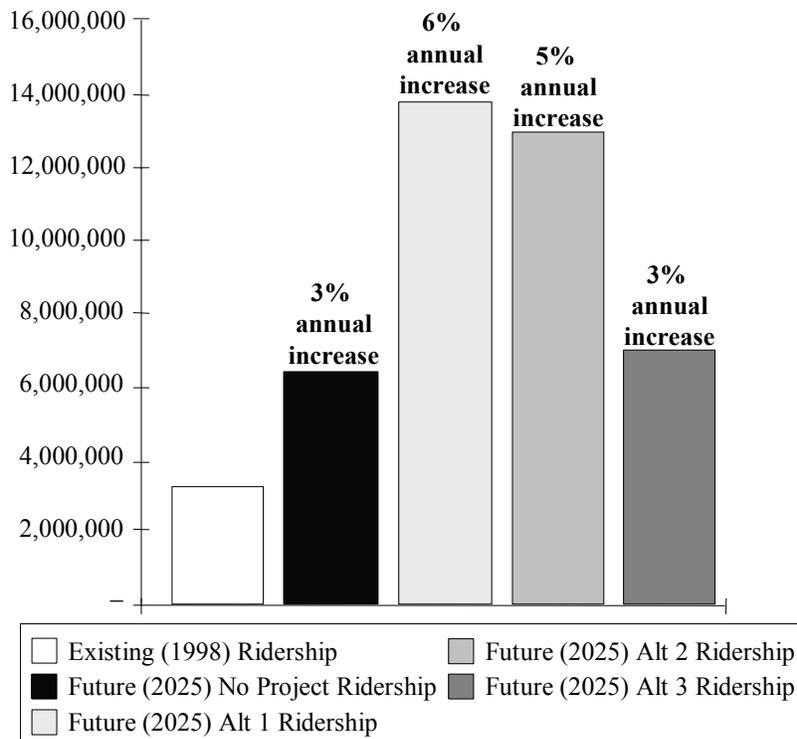
Mode Shares by County

Person trips by mode and county were evaluated for each alternative. As expected, there are no significant differences in mode shares by county from one alternative to another, but there are some changes in all modes that appear in counties with increased ferry services, such as Marin and Alameda. All counties have slightly higher ferry mode shares in each alternative, compared to the future no project alternative, except Solano County, which decreases slightly. This is a result of the assumption that there will be \$2 parking charge on all ferry terminals in each alternative, but free parking in the future no project alternative.

Summary of Ridership Forecasts

Ridership forecasts were prepared by route and corridor for each future alternative and compared to both the future No-Project alternative and the existing ridership. Alternative 1 produced the highest ridership (49,210 trips per day), with Alternative 2 producing almost as much ridership (45,133 trips per day). Alternative 3 produced only slightly higher ridership (25,385 trips per day) than the future no project alternative (23,238 trips per day). Figure 1 presents a comparison of the annual ridership for each of the alternatives.

Figure 1. Annual Ferry Riders by Year and Alternative
Average Annual Ferry Riders



Ridership by Mode of Access and Egress

Mode of access for each alternative and egress was evaluated for each ferry terminal and each alternative. In all three future alternatives, drive access is the predominant mode of access on a systemwide basis (more than 60 percent of the total trips in all alternatives). The highest drive access alternative is the Comprehensive Service (with 66 percent), the highest walk access alternative is the Enhanced Existing Service (with 24 percent), and the highest transit access alternative is the Expanded Service (with 17 percent).

Ridership by Purpose and Day of Week

Ridership is produced for weekdays from the WTA forecasting model by trip purpose for each alternative. The home-based work (HBW), shopping (HBSH), and social-recreational (HBSR) trips are estimated using the WTA mode choice models; and non-home-based and school trips are estimated from the MTC mode choice model. Weekend ridership is calculated as a function of the weekday ridership by trip purpose and is provided in these tables as well.

The average weekday work trips range from 63 percent in the Expanded Service alternative to 81 percent in the Enhanced Existing Service alternative. The HBSR trips are twice the HBSH trips in every alternative, ranging from eight percent in the Enhanced Existing Service alternative to 15 percent in both the Expanded and Comprehensive Service alternatives. The total weekend trips are lower in the Enhanced Existing Service alternative than the other alternatives, because of the lower frequency of non-work trips.

Ridership by Direction and Time Period

Ridership was produced by direction and time period for weekdays from the WTA forecasting model for each alternative. The directional factors for each time period are derived from the on-board survey data collected in the fall 2001 and applied to each alternative by corridor. The total weekday peak trips range from 57 percent in the Comprehensive Service alternative to 71 percent in the Enhanced Existing Service alternative. The peak direction of travel in the a.m. peak period is higher in every alternative than the peak direction of travel for the p.m. peak period, which is more balanced by direction (ranging from 33 percent in the Enhanced Existing Service alternative to 28 and 26 percent in both the Expanded and Comprehensive Service alternatives, respectively). The total weekend trips are lower in the Enhanced Existing Service alternative than the other alternatives, because of the lower frequency of non-work trips.

Parking Demand and Supply

Parking demand is developed from data on numbers of trips that drive to a ferry terminal and factors from the on-board survey data that allow us to convert these trips into numbers of vehicle that park at a ferry terminal. These factors are derived for existing ferry terminals and applied to all terminals in a corridor for future alternatives. Average

auto occupancy of drive access trips is applied to drive access trips to produce drive access vehicles for all ferry terminals. Trips that park outside the ferry terminals (percent overflow) and trips that drive to the station to drop someone off (percent kiss and ride) are subtracted from the overall total of vehicles that park at a station to produce the number of vehicles that park on site. This demand is then subtracted from the parking supply, which is provided by PTM consultants for each future ferry terminal to produce utilization factors for each terminal. Systemwide utilization is highest in the Enhanced Existing Service alternative (85 percent), with two of six terminals predicting higher demand than supply. Utilization for the Expanded Service alternative is 64 percent, with four of 18 terminals predicting higher demand than supply and for the Comprehensive Service alternative is 60 percent, with four of 23 terminals predicting higher demand than supply.

Modal Diversion

Ferry routes were combined into screenlines for an analysis of modal diversion. The ferry ridership is combined with auto, rail, and bus trips from the WTA forecasting model to produce estimates of person and vehicle trips across major screenlines in the Bay Area, developed for the purposes of this study.

In both the Comprehensive and Expanded Service alternatives, ferry services divert more trips from highway than from other transit (54 and 33 percent more highway trips diverted than transit trips, respectively). In the two rail corridors (San Francisco/San Mateo county line and Bay Bridge), the majority of diversion from other transit is from rail and not bus services. Not surprisingly, the screenlines with the most modal diversion to ferry are the Golden Gate Bridge, Bay Bridge, and the San Francisco/San Mateo county line.

Vehicle Miles Traveled

VMT is calculated as the traffic volume (output from a traffic assignment) multiplied by the distance (in miles) for every link in the MTC regional highway network. Intrazonal VMT and transit drive access VMT are reported separately, because these are calculated as a post-process to the WTA ridership forecasting model. Intrazonal VMT represents the trips within a TAZ multiplied by the average trip length (in miles) for intrazonal trips. These are calculated separately, because intrazonal trips are not assigned to the highway network during the traffic assignment process. Transit drive access trips are calculated as the number of vehicles that drive to access transit services multiplied by the trip distance for each of these trips (in miles). These are also calculated separately, because transit drive access trips are not assigned to the highway network during the traffic assignment process. Alternative 1 has the lowest VMT.

Sensitivity Analysis

All of the sensitivity runs are based on the network assumptions included in Alternative 2 (Expanded Service), except Alternatives 6 and 9, which are based on the network

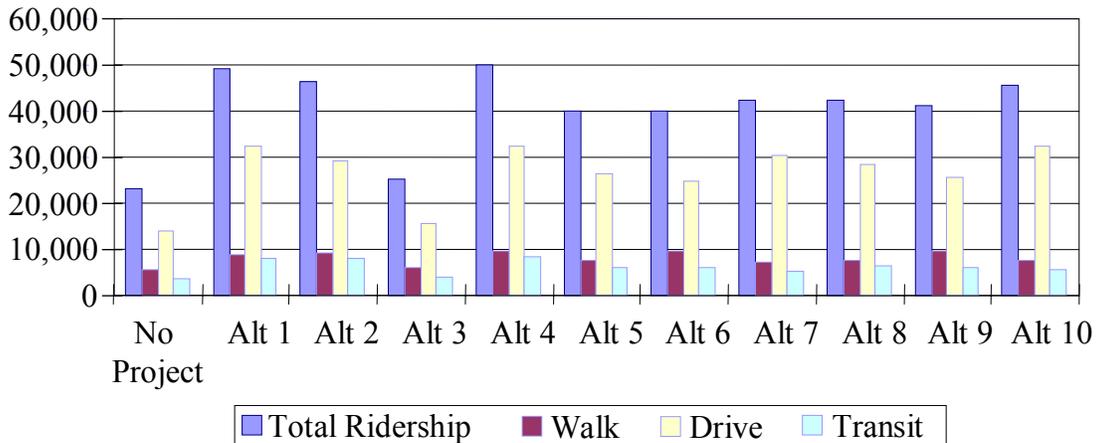
assumptions in Alternative 3 (Enhanced Existing Service). Each of the runs tests a specific assumption within this alternative. The sensitivity runs completed include the following tests:

- **Alternative 4 – Pricing Options.** This sensitivity run increased tolls on all state bridges and included a \$2 parking charge for BART park-and-ride lots at stations. The tolls were increased by \$1 on each bridge, with the Golden Gate Bridge increased to \$5.
- **Alternative 5 – New Ferry Headways.** Increased headways on most routes are implemented in the transit networks by increasing maximum wait times on individual routes. The wait time is determined as the lesser half the headway or the maximum wait time for each route. Maximum wait time assumptions in the model were changed to reflect the increase in headways.
- **Alternative 6 – Alternative Transit Investment.** This alternative includes offering alternative transit services for the same origin-destination (O-D) markets proposed ferry routes service. Headways and fares are set equal to competing ferry schedules for a consistent comparison. Parking is provided for bus services to match catchment areas of nearby ferry terminals. Parking is unconstrained in the model run. There is a \$2 parking charge at all alternative bus stations to match the \$2 parking charge at ferry terminals.
- **Alternative 7 – Alternative Transit with Expanded Ferry.** This alternative is a combination of Alternatives 6 and Alternative 2. Alternative bus service from Alternative 6 (Alternative Transit Investment) is added to proposed ferry service in Alternative 2 (Expanded Ferry Service).
- **Alternative 8 – Pricing Options with New Ferry Headways.** This alternative is a combination of Alternatives 4 and 5. This alternative includes increased tolls, \$2 BART parking charges, and reduced ferry headways. The one other change in this alternative is that the Martinez-Benicia route has been removed in favor of the Antioch/Pittsburg-Martinez-San Francisco route.
- **Alternative 9 – Alternative Transit Investment with Pricing Options.** This alternative is a combination of Alternatives 4 and 6. This alternative includes increased tolls, \$2 BART parking charges, and alternative bus service that replaces ferry services.
- **Alternative 10 – Alternative Transit Investment with Expanded Ferry and Pricing Options.** This alternative is a combination of Alternatives 4 and 7. This alternative includes increased tolls, \$2 BART parking charges, bus service from Alternative 6, and the Expanded Ferry Service from Alternative 2.

Summary of Ridership Forecasts

Figure 2 shows weekday ridership forecasts for each of the ten alternatives. The ridership forecasts are compared by route and corridor to the alternative used as the basis for the sensitivity run. For Alternatives 4, 5, 7, and 8, the base alternative is Alternative 2 (Expanded Service). For Alternatives 6 and 9, the base alternative is Alternative 3 (Enhanced Service Alternative). Alternative 4 is the only alternative that results in an increase of ferry ridership compared to the preferred alternative (Alternative 2).

**Figure 2. Total Weekday Ferry Riders / Riders by Mode of Access (Year 2025)
Number of Weekday Riders**



Mode of Access

A comparison of the systemwide mode of access for the ferry shows a slight increase in drive access for Alternative 4 (see figure 2), indicating that the toll increases may be converting some existing drive alone or carpool trips to drive access to ferry trips, and the BART parking charges may be converting some existing drive access to BART users to drive access to ferry users. The comparison also shows a decrease in transit access for Alternative 5, indicating that the increased ferry headways are converting some transit access to ferry users to other transit modes.

Modal Diversion

Ferry ridership is combined with auto, rail, and bus trips from the WTA forecasting model to produce estimates of person trips across major screenlines in the Bay Area, developed for the purposes of this study.

Figures 3 and 4 present the changes in person trips across the Bay Bridge and Golden Gate screenlines, respectively. Alternative 4 and 10 are the only alternatives that result in an increase in ferry transit across these screenlines, resulting from increases in tolls on the bridges. The effects of increasing headways and wait times for ferries in Alternative 5 are to significantly decrease ferry ridership across the Bay Bridge and the Golden Gate Bridge. The effects of providing alternative transit investments (buses) in ferry markets in Alternative 6 are to significantly increase person trips on alternative transit modes across all screenlines. The effects of combining the alternative transit investment with expanded ferry services in Alternative 7 are to significantly increase person trips on alternative transit modes across all screenlines. The effects of combining the pricing options with new ferry headways in Alternative 8 are to significantly decrease BART ridership across the Bay Bridge and the San Mateo/San Francisco county line. The effects of providing alternative transit investments (buses) in ferry markets along with expanded ferry services in Alternative 9 are to significantly decrease BART ridership

across the Bay Bridge and the San Mateo/San Francisco county line. This also results in an increase in highway trips across all bridges.

Figure 3. Changes in Person Trips by Mode on the Bay Bridge Screenline

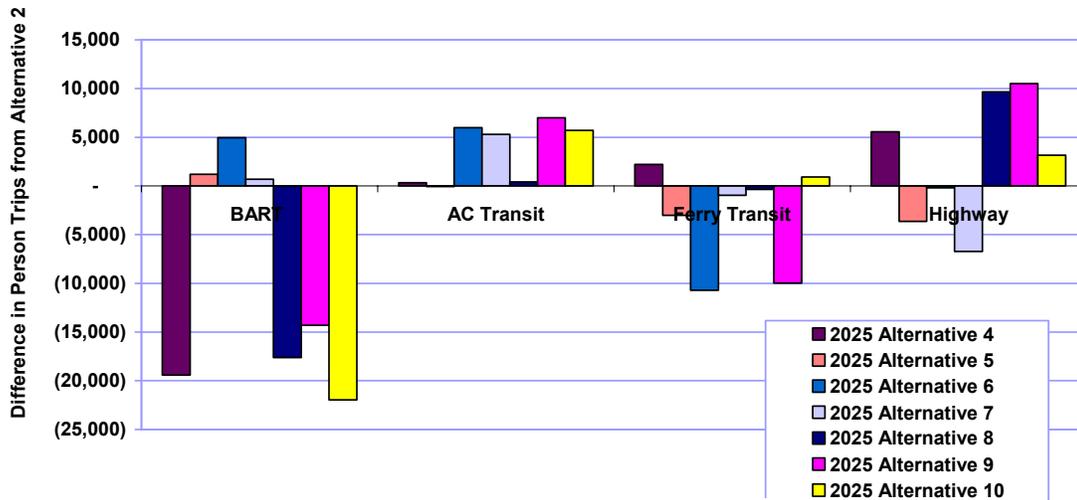
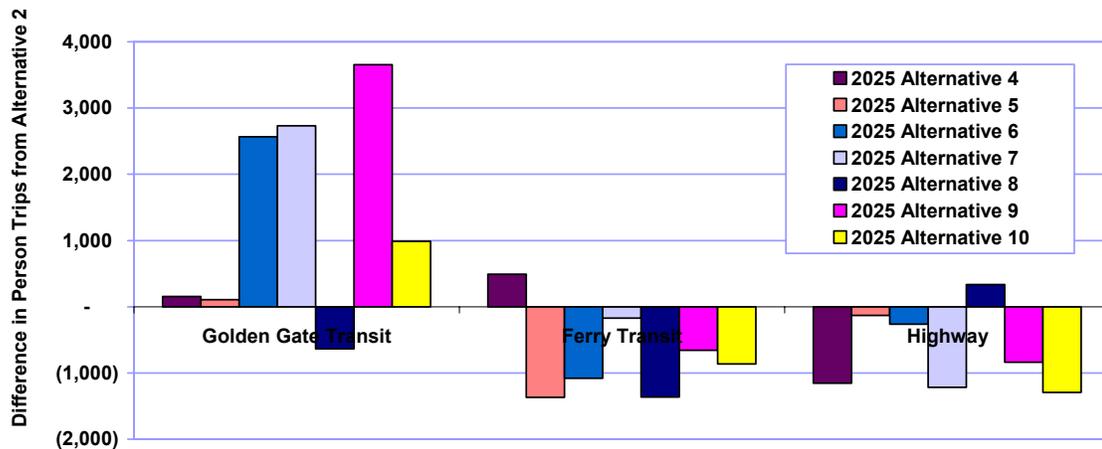


Figure 4. Changes in Person Trips by Mode on the Golden Gate Screenline



Summary of User Benefits

Average weekday daily user benefits are calculated using the Federal Transit Administration (FTA) procedure, which also is implemented by the MTC for regional planning studies. This method provides a means to compare alternatives across multiple modes. Values of time used in this analysis to convert travel time for existing and new users are derived from the mode choice model and weighted across trip purposes. Table 1 presents a summary of these results for the three original alternatives and for the six additional sensitivity runs. The Expanded Service alternative provides the highest user benefits, with the majority of these benefits for auto users and the Pricing Options alternative provides the worst user benefits.

Table 1. Average Weekday Daily User Benefits (2001 \$)

Alternative	Description	Travel Time	Out-of-Pocket Costs	Total
1	Comprehensive Service	\$137,303	-\$3,283	\$134,020
2	Expanded Service	\$197,765	\$2,114	\$199,879
3	Enhanced Existing Service	\$69,995	-\$10,180	\$59,815
4	Pricing Options	-\$156,912	-\$761,112	-\$918,024
5	New Ferry Headways	-\$52,673	-\$3,560	-\$56,232
6	Alternative Transit Investment	-\$314,723	-\$15,054	-\$329,777
7	Alternative Transit with Expanded Ferry	\$162,601	-\$11,358	\$151,243
8	Pricing Options with New Ferry Headways	-\$194,461	-\$764,478	-\$958,939
9	Alternative Transit Investment with Pricing Options	-\$313,526	-\$782,274	-\$1,095,800
10	Alternative Transit with Expanded Ferry and Pricing Options	-\$139,931	-\$748,647	-\$888,578

User Benefits and Multimodal Project Evaluation

Jim Ryan, *Federal Transit Administration*

Abstract. This presentation will describe the latest developments in the calculation of user benefits for Federal Transit Administration New Starts applications. Discussions will cover insights gained from the evaluation of New Starts projects in the fall of 2002 and ideas for future directions.

9th TRB Conference on the Application of Transportation Planning Methods
6-10 April 2003, Baton Rouge, Louisiana
Session 8: Smart Growth

Quantitative Assessment of the Maryland Smart Growth Initiative

Brad S. Lane

No Abstract Available.

9th TRB Conference on the Application of Transportation Planning Methods
6-10 April 2003, Baton Rouge, Louisiana
Session 8: Smart Growth

Chicago Balanced Growth Study

Ronald Shimizu

No Abstract Available.

9th TRB Conference on the Application of Transportation Planning Methods
6-10 April 2003, Baton Rouge, Louisiana
Session 8: Smart Growth

Filling Up Faster: Induced Travel Demand Implication for Transportation and Land

Ria Hutabarat

No abstract available.

9th TRB Conference on the Application of Transportation Planning Methods
6-10 April 2003, Baton Rouge, Louisiana
Session 8: Smart Growth

Chicago Metropolis: The Business Community Develops and Integrated Land Use/ Transportation Plan

Brian Grady

No abstract available.

9th TRB Conference on the Application of Transportation Planning Methods
6-10 April 2003, Baton Rouge, Louisiana
Session 8: Smart Growth

Coordination of Land Use/Transportation Studies at the Parish and Sub-Parish Level

Lynn Dupont

No abstract available.

Quantifying Access Management Benefits using Traffic Simulation

Jerry K. Shadewald, *HNTB* and Clyde Prem, *AICP*

Abstract. The San Antonio - Bexar County Metropolitan Planning Organization has identified several developing corridors to be designed using access management techniques. This action is a result of several existing arterial corridors which already have congestion problems associated with uncontrolled access to adjacent land uses. The Bitters Road corridor in northern San Antonio is a five-lane arterial that has 37 access points and five at-grade signalized intersections within a one-half mile section. Several businesses along Bitters Road resort to hiring off-duty law enforcement officers to direct traffic to ensure vehicles can safely enter their business. A traffic analysis was conducted to quantify the extent of delay experienced along Bitters Road and the expected improvements to traffic operations if access management techniques were implemented.

These expected improvements to the existing corridor would be used to justify the use of access management techniques to the developing corridors within the San Antonio area. The traffic analysis began with analyzing the existing conditions. Two traffic simulation programs, Netsim and Synchro, were utilized to develop AM and PM peak hour models of the corridor. Two conceptual scenarios were also developed and analyzed using both software programs. The first scenario was a retro-fit of the existing condition, with many driveways consolidated or eliminated. The second scenario removed all driveways and utilized parallel backage roads to provide access to the adjacent land uses. Several measures of effectiveness including travel speed, delay, emissions and volume were used to estimate the benefits of the two scenarios. The benefits of the scenarios were then used to predict the likely traffic operations along the developing corridors if access management techniques were utilized.

The San Antonio-Bexar County Major Thoroughfare Plan was developed to provide information on the need to preserve the integrity of urban arterial corridors for the function of mobility. As land development in San Antonio continues to occur, preserving the mobility function of arterial streets becomes increasingly difficult. The Thoroughfare Plan included the analysis of a number of specific travel corridors in the San Antonio region. Access management standards were developed and applied through traffic simulation to several corridors to analyze the benefits of implementing such standards. Bitters Road serves as an arterial within the San Antonio roadway system.

The Bitters Road corridor of San Antonio currently has very poor access control in the vicinity of the U.S. 281 interchange. The analysis was intended to quantify the expected operational improvements from implementing access management techniques along Bitters Road. The analysis was conducted on a 0.52 mile section of Bitters Road between West Avenue and Heimer Road including the interchange of Bitters Road with the U.S. 281 frontage roads (see Figure 1). Both AM and PM simulations were performed on three

scenarios consisting of existing geometric conditions, improved access control via retro-fits and an idealistic full-access controlled reconstruction.

Two traffic simulation programs were used in the analysis, Synchro/Simtraffic and Netsim (Ver. 5.0). Netsim, is generally considered to be a proven simulation package in the United States, but offers no traffic signal optimization features. Synchro specializes in the analysis and optimization of traffic networks and provides simulation through Simtraffic.

Trip Generation and Turning Movements

The first step in the analysis was to identify the land uses adjacent to Bitters Road. These land use types were combined with parcel and building size information gathered from the aerial photography shown in Figure 1. The Institute of Transportation Engineers Trip Generation Manual, Version 61 was used to estimate the number of trips into and out of each land use type.

Table 1- Trip Generation Output

Zone	Description	Area ¹	Units	AM		PM	
				In	Out	In	Out
1	Multi-Family Residential	220	DU ⁴	18	94	91	45
2	Multi-Family Residential	310	DU ⁴	25	133	129	63
3	Multi-Tenant Retail	30	1000 SF	19	12	54	58
4	Gas/Conv. Store	1	1000 SF	40	38	48	48
5	Auto Lube	4	Bays ⁵	10	8	10	8
6	Fast Food w/ Drive Thru	2.27	1000 SF	58	55	40	36
7	Single-Family Residential	7	DU	1	4	5	3
8	Multi-Tenant Retail	104.4	1000 SF	66	42	187	203
9	Embassy Theatre	34.7	1000 SF	0	0	84	47
10	Fast Food w/ Drive Thru	1.35	1000 SF	34	33	24	22
11	Fast Food w/ Drive Thru	2.12	1000 SF	54	52	37	34
12	Sit-Down Restaurant	9	1000 SF	43	40	59	39
13	Vacant ²			0	0	0	0
14	Fast Food w/ Drive Thru	1.25	1000 SF	32	31	22	20
15	Auto Lube	4	Bays ⁵	10	8	10	8
16	Sit-Down Restaurant	2.9	1000 SF	14	13	19	13
17	Specialty Retail ³	1	1000 SF	3	3	1	1
18	Multi-Tenant Retail	88.5	1000 SF	56	36	159	172
19	Bowling Alley	42.5	1000 SF	80	53	53	98
19A	Dietary Drug Store	13.4	1000 SF	25	18	50	52
20	Gas/Conv. Store	3.12	1000 SF	124	119	150	150
21	Fast Food w/ Drive Thru	2.72	1000 SF	69	66	47	44
22	Target Store	71.4	1000 SF	67	64	134	139
23	Multi-Tenant Retail	109.9	1000 SF	69	44	197	214
24	Multi-Tenant Retail	76.2	1000 SF	48	31	137	148

- 1 Gross square footage estimated from aerial photography.
- 2 Under renovation currently. Previously vacant.
- 3 Open-air pottery shop. AM Peak Hour generation estimates provided for peak hour of generator only.
- 4 Number of residential dwelling units estimated by San Antonio staff.
- 5 Number of service bays estimated based on size of buildings.
- 6 No AM Peak Hour generation estimates were provided. PM generation used for both peak hours.
- 7 Hourly variation in traffic, page 1335. Residential assumed to have lower trip rates (60% of AM and PM) while restaurants have a higher rate (120% of AM and PM).

These trip generation estimates were assigned to driveways in order to approximate movements onto and off of the surface street system. Table 1 shows the number of trips into

¹ Trip Generation, 6th Edition, Institute of Transportation Engineers, 525 School St., S.W. Suite 410, Washington, D.C., 20024, 1997.

and out of each parcel for AM and PM peak hours. These trips were then combined with intersection traffic counts to produce turning movements at intersections and driveways along Bitters Road.

Existing Conditions

The three alternatives analyzed differ in the level of access management imposed on businesses adjacent to Bitters Road between West Avenue and Heimer Road. The first alternative analyzed traffic operations as they currently exist. This includes very close driveway spacing as a result of all businesses having unique and often multiple access points to Bitters Road. The cross-section of Bitters Road is five lanes with a center two-way left-turn lane (TWLTL). Simulation of a TWLTL is problematic using both Simtraffic and Netsim. This was overcome through the use of short left turn bays added to the four-lane cross-section at all driveways. Figure 2 shows the Simtraffic model for the existing alternative. Notice that 46 driveways exist within the study area, of which 23 access directly with Bitters Road between West Avenue and Heimer Road.

Figure 1 - Bitters Road Study Area



Access Management

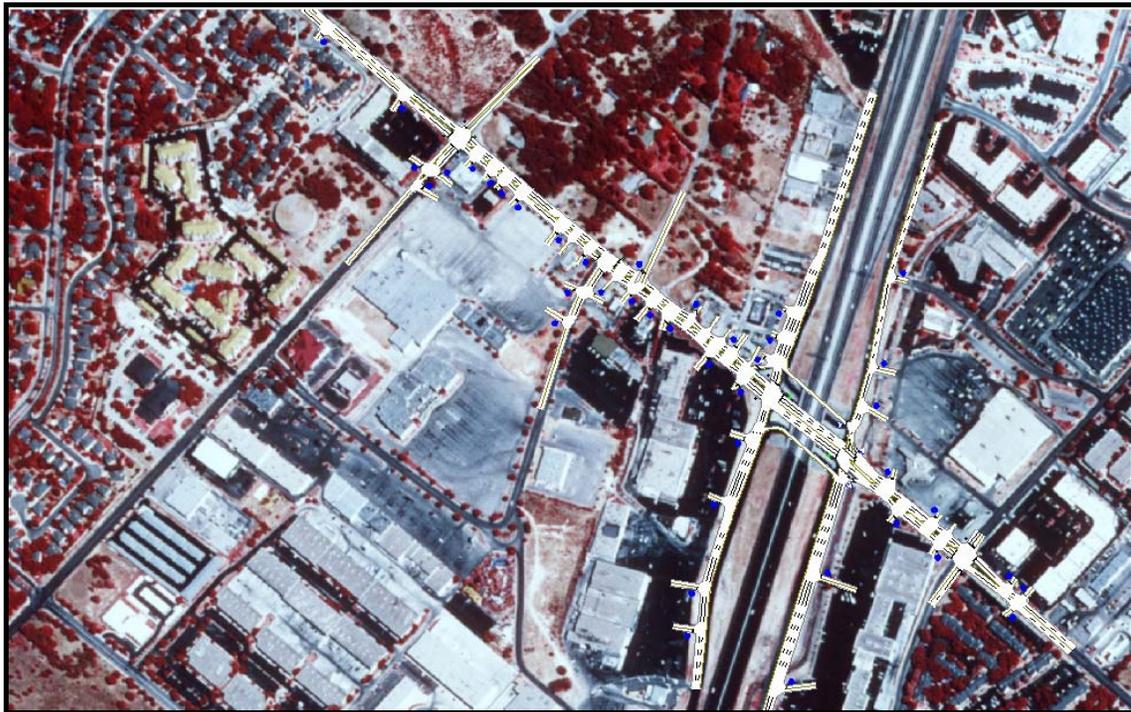
The high number of driveways that intersect with Bitters Road cause several undesirable operating conditions. According to the Highway Capacity Manual 2000², the free flow speed of a multi-lane facility decreases 2.5 miles per hour (mph) for every 10 access points

² Highway Capacity Manual 2000, Transportation Research Board, National Research Council, Washington, D.C., 2000.

per mile on the right side of the road. Bitters Road contains 22 right-side access points eastbound between West Avenue and Heimer Road, a distance of 0.52 miles. This results in a density of over 40 access points per mile and a reduction in free-flow speed of approximately 10 mph. The westbound direction has 15 access points that contribute a 7 mph reduction in free-flow speed.

The American Association of State Highway and Transportation Officials (AASHTO)³ states that accident rates increase on arterial streets as the number of adjacent businesses and at-grade intersections increase. The study area contains 15 businesses with direct access to Bitters Road with 5 at-grade intersections in the 0.52 mile stretch. The expected accident rate is 40 percent higher than the rate of a similar roadway with no business access and 4 at-grade intersections. The Access Management Handbook⁴ reports the findings of several case studies in which a congested urban arterial was reconstructed using access management techniques. The findings indicate that highway capacity is increased at locations where access management techniques

Figure 2 - Existing Conditions



were incorporated into the reconstruction projects. Additionally, accident rates tended to decrease while retail business along the corridor increased after the access management projects were completed.

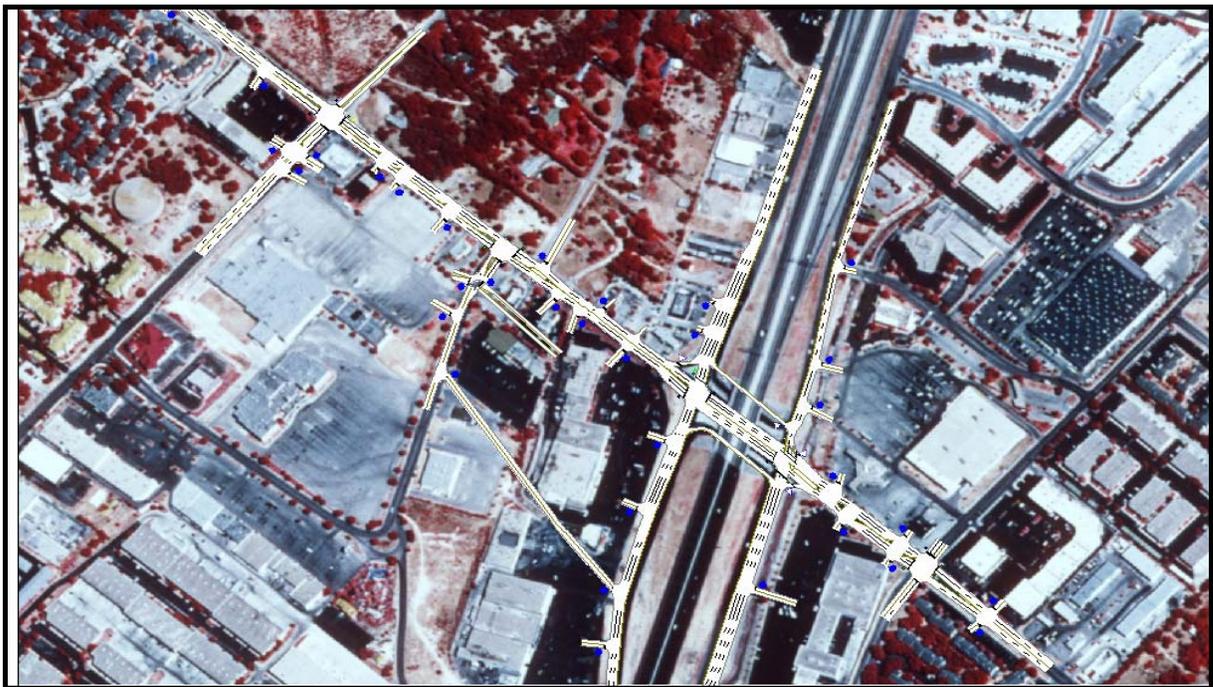
³ A Policy on Geometric Design of Highways and Streets, American Association of State and Highway Transportation Officials, 444 North Capitol Street, N.W., Suite 249, Washington, D.C., 1995.

⁴ Access Management Handbook, Center for Transportation Research and Education, Iowa State University, 2901 S. Loop Drive, Ames, Iowa, 2000.

Access-Controlled Alternatives

The second alternative simulated the effects of improved access control, reducing the number of driveways along the entire project extent from West Avenue to Heimer Road as shown in Figure 3. This alternative represents a level of access management that could be achieved by ‘retro-fitting’ good traffic engineering and access management practices into the existing corridor. Ten driveways are eliminated between West Avenue and the U.S. 281 interchange and two driveways are eliminated between U.S. 281 and Heimer Road. This reduces the density from 40 to 25 access points per mile eastbound and from 30 to 17 access points per mile westbound. Additionally, a center median is added on Bitters Road from Embassy Oaks to the intersection of U.S. 281 Southbound Access Road. This results in right-in, right-out maneuvers only at those driveways between Embassy Oaks and the U.S. 281 interchange. A ‘backage’ road connecting Embassy Oaks with developments to the east provides access to those businesses for vehicles traveling west on Bitters Road.

Figure 3 - Improved Access-Controlled Alternative



The third alternative represents the hypothetical condition where recommended intersection and driveway spacing could be implemented. The full access control alternative installs a center median between West Avenue and Heimer Road and eliminates all driveway access to Bitters Road from all adjacent parcels (see Figure 4). Access density is reduced to 10 points per mile in both east and westbound directions. Access is provided through the use of backage roads that connect the land uses to streets intersecting with Bitters Road. These backage roads carry traffic through existing parking lots, allowing for full access to the surrounding land uses.

The first backage road is located south of Bitters Road from West Avenue, across Embassy Oaks, to the Southbound U.S. 281 frontage road. This backage road would provide access to

all parcels south of Bitters Road. The second backage road provides access to businesses north of Bitters Road and is located between the Southbound Access Road north of the Bitters/U.S. 281 interchange and the entrance to Hill Country Village located east of the existing Embassy Oaks intersection. The center median is continuous from West Avenue to the U.S. 281 interchange, providing right-in, right-out access at Embassy Oaks and the Hill Country Village intersections. The center median is also installed from the U.S. 281 interchange to Heimer Road. Access to adjacent parcels is provided only through the use of parking lot connections to Heimer Road.

Simulation Models

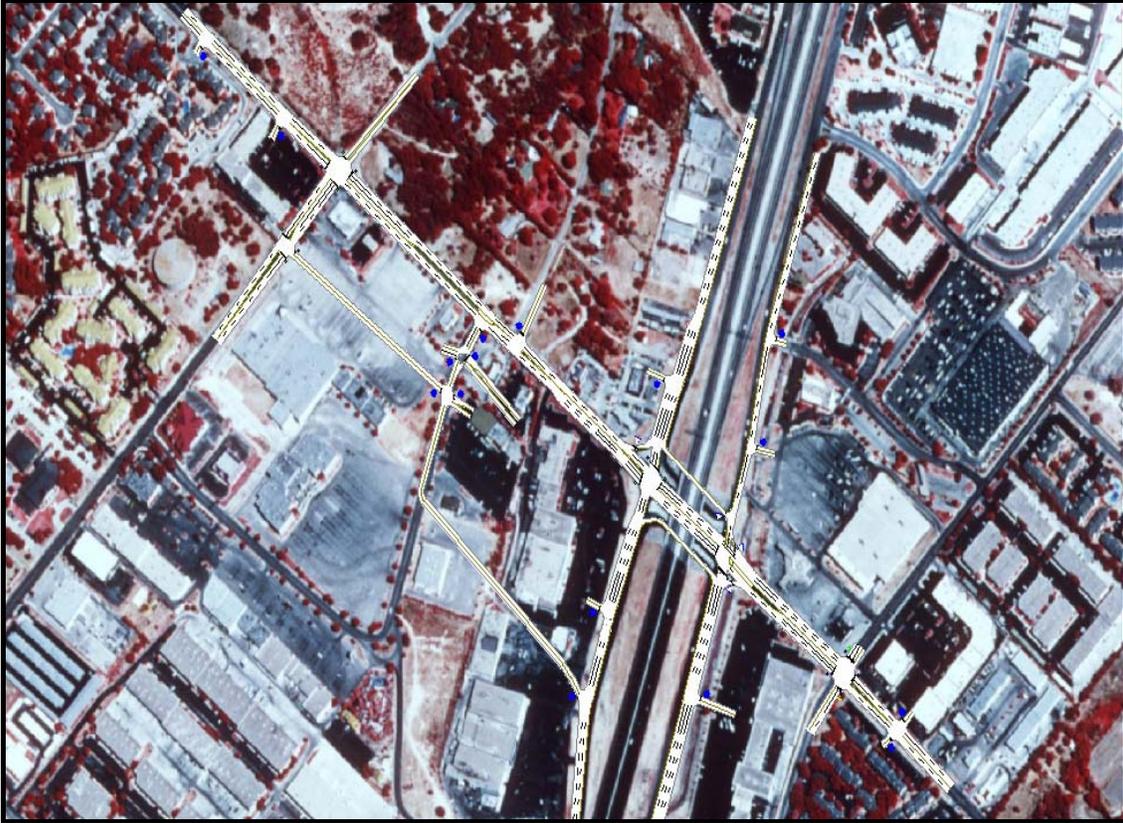
The simulation models were used to measure the benefits associated with improved corridor operations and travel times as well as possible disbenefits associated with longer trip lengths resulting from the access control measures. Once all traffic movements and infrastructure changes were estimated for the two analysis periods, a Synchro model was produced. Synchro requires both the hourly volume of traffic as well as the physical infrastructure (number of lanes, length of turn bays, traffic control, etc.).

Traffic signal phasing was provided while cycle lengths and offsets were optimized using Synchro. Simtraffic was used to simulate the networks for both AM and PM proposed alternatives. For the existing alternative, the close spacing of driveways produced link lengths of less than 100 feet in many locations along the mainline of Bitters Road. These short links stressed the car-following theories within Simtraffic, resulting in vehicles not progressing through the network but rather stalling at intersections for the remainder of the simulation. Similar experience has been noted by Dittberner and Kerns⁵. Therefore, Synchro/Simtraffic results are not available for the existing AM and PM scenarios.

The results of the remaining 4 scenarios are shown in Table 2. Netsim networks were then created using the data stored in Synchro for the 6 scenarios shown in Table 2. The Netsim simulation appears more reflective of existing and anticipated conditions than the Simtraffic results for this particular corridor. All scenarios were calibrated to counted traffic volumes and observed queuing and travel speed conditions. The simulations for all scenarios were performed with three random numbers with results in Table 2 representing the average of the three simulations.

⁵ Randy A. Dittberner, P.E., PTOE. and Robert T. Kerns, P.E., PTOE, Traffic Simulation in Congested Urban Networks: Pennsylvania Avenue Case Study, ITE Journal, Vol. 72, Number 10, October, 2002.

Figure 4 - Full Access-Controlled Alternative



Analysis Results

The measures of effectiveness and analysis results in Table 2 were used for comparing the three alternatives. These measures reflect the mobility function of Bitters Road as an arterial within the San Antonio roadway system. In order to provide mobility, higher travel speeds and higher traffic volumes along with lower travel time delays are considered desirable. Improving environmental components such as emissions, fuel consumption and fuel efficiency are also considered benefits within the study.

The system-wide measures show that both access controlled alternatives generally improve the operations within the modeled area. This is indicated by reduced delays and travel times coupled with increased traffic volumes and speeds through the system.

Table 2 - Measures of Effectiveness from Synchro/Simtraffic and Netsim

Time Period	Simulation Alternative		System Measures of Effectiveness				Bitters Road Speeds				
			Total Delay		Volume	Travel Time	Fuel Eff.	West of U.S. 281		East of U.S. 281	
			Hours	Sec/Veh	Vehicles	VHT	MPG	EB	WB	EB	WB
AM	Synchro	Existing	n/a	n/a	n/a	n/a	n/a				
		Improved Access Control	610	330	6,600	710	5	7.3		6.8	
		Full Access Control	240	120	7,200	360	8	14.2		8.5	
	Netsim	Existing	440	295	5,400	515	3	2.4	7.8	23.8	13.2
		Improved Access Control	395	230	6,750	490	3	4.3	23.9	19.2	7.7
		Full Access Control	105	50	7,900	215	6	25.5	27.0	20.6	18.2
PM	Synchro	Existing	n/a	n/a	n/a	n/a	n/a				
		Improved Access Control	990	450	8,000	1,110	4	8.6		7.0	
		Full Access Control	880	380	8,300	1,000	5	9.5		3.1	
	Netsim	Existing	635	460	5,000	700	2	2.1	2.3	11.0	2.8
		Improved Access Control	580	290	7,250	670	2	2.3	4.3	16.8	10.9
		Full Access Control	185	65	10,150	320	5	17.4	25.4	19.0	16.1



The improved access control alternative results show an increased level of service when compared with the base condition. Simulation results from Netsim indicate an increase in traffic volume of 25 to 45 percent. This increase in volume due to the reduction in access points is approximately equal to adding one additional lane in each direction to Bitters Road.

This additional volume indicates trips from parallel facilities may be rerouting to the lower travel time rerouting is a combination of trips that previously avoided Bitters Road due to the level of congestion and trips now using Bitters Road to avoid other congested facilities. Those trips avoiding other congested facilities increase the miles traveled through the San Antonio system while the trips routed back to Bitters decrease the system-wide miles traveled.

The Netsim results also show a decrease in the total delay per vehicle (65 to 170 seconds per vehicle) coupled with a more substantial reduction in stop delay per vehicle (100 to 200 seconds per vehicle). Simulated speeds have also increased 20 to 33 percent. The total time (VHT) traveled through the system has decreased only slightly while the number of vehicles traveling through the system has increased dramatically. The improved access controlled alternative shows virtually no impact to environmental measures.

The full access controlled alternative shows greatly improved operations within the Bitters Road corridor for both AM and PM peak hours using both Netsim and Simtraffic. Simulated traffic volumes increase by nearly 50 to over 100 percent compared with the existing condition, equivalent to one to two additional lanes of existing capacity. The total

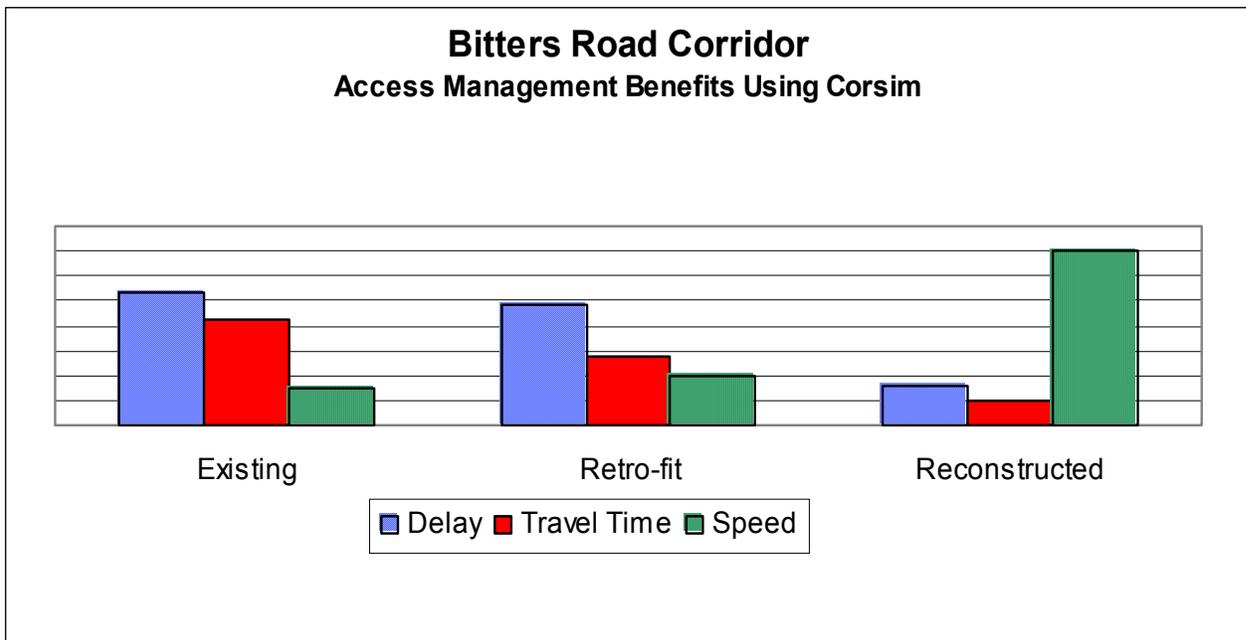
delay and stop delay per vehicle decrease by 83 to 91 percent when compared with the existing scenario.

The increase in Bitters Road speeds as simulated in Netsim from less than 3 miles per hour (mph) in the base alternative to between 17 and 27 mph in the full access controlled alternative implies the improvements would greatly increase the mobility provided by Bitters Road within the study area. Despite the large increase in the number of vehicles, the increased fuel efficiency and travel speeds result in a 30 to 40 percent reduction in fuel consumption. Figure 5 shows the relative change in measures of effectiveness between the three scenarios for the PM peak hour.

Study Conclusions

The measures of effectiveness indicate that the full access controlled alternative helps Bitters Road achieve the functional goals of an arterial, resulting in a more desirable level of service for traffic. The number of vehicles moving through the system could increase 50 to 100 percent with substantially higher speeds while significantly reducing delay and fuel consumption with minimal changes to the Bitters Road mainline. Access is still provided into surrounding developments with travel times to these destinations likely to decrease despite the lack of direct access. However, the full access controlled alternative requires more capital investment than the improved access controlled alternative. The improved access controlled alternative also provides benefits, but at a smaller scale than the full access

Figure 5 - PM Peak Hour MOE Comparisons



controlled alternative. The access management techniques achieve higher travel speeds and capacities while delays decrease through the system. The capital improvements required for this alternative are considerably less than those required for the full access controlled

alternative. Although the full access controlled alternative would result in more favorable traffic operations, the increased capital cost may offset the benefits.

Simulation Model Notes

The use of simulation models had not been clearly outlined for the use of comparing access management techniques in previous literature. Therefore, this study utilized two commercially available traffic simulation packages, Synchro/Simtraffic and Netsim in an attempt to determine likely traffic impacts. Synchro/Simtraffic allowed for quicker construction of the simulation network as well as traffic signal optimization. Both Simtraffic and Netsim were unable to explicitly model two-way left-turn lanes. This study did conclude that Synchro/Simtraffic had more difficulty in simulating the very congested conditions of the existing scenario.

The analysis results indicate that both simulation packages provided the same general conclusion of the full access-controlled scenario providing better traffic operating conditions than the retro-fit scenario, which in turn was an improvement over the existing condition. However, a sensitivity analysis between the two packages that would deduce how well the two programs quantified the impacts of any particular access management technique, such as consolidating one driveway, was not performed.

Other commercially available simulation packages such as Vissim, Paramics, Integration and MITSIM were not available for the study. Indications are that these programs would have provided similar recommendations as provided by Simtraffic and Netsim.

SH 114 / SH 121 Dynamic Access Management and Planning

Phillip Ullman, P.E., Brian Swindell, P.E., and Will Hagood, P.E., *HDR Engineering, Inc.*, and Curtis Hanan, P.E., *Texas Department of Transportation*

Abstract: Attempting to relieve congestion within a growing metropolitan area usually requires a dynamic study process. Add extensive new development within a super-interchange and you have a planning and political nightmare where mobility and local access concerns compete for emphasis.

Texas 114 and Texas 121 are multi-lane freeways, which merge for two miles forming the nexus of a super-interchange of seven freeway segments. Upgrading the super-interchange to accommodate significant traffic growth on each of the seven freeway segments was the focus of a major transportation study in the Dallas/ Fort Worth Metroplex for the Texas Department of Transportation.

While planning for over 100% growth along the seven already congested freeway segments which tie into the super-interchange impacts to major trip generators and developing commercial properties greatly affected planning activities. The project, north of DFW International Airport, consists of adding mainlane and "Managed Lane" capacity, modification of four freeway-to-freeway multilevel directional interchanges, three segments of collector distributor roadways, three braided ramps, numerous diamond interchanges and a connection to regional rail service. Major trip generators within the project area include a large retail mall (Grapevine Mills), DFW Airport (the 5th most active airport in the world), a convention center, a new entertainment park (Opryland), a possible major NFL new stadium (to possibly replace Texas Stadium) and an extensive restaurant district along the corridor.

The project required complex regional travel demand modeling to determine projected traffic volumes and traffic pattern changes expected to occur over the next 25 years. Also, complex vehicle behavior analysis was required utilizing traffic simulation models. Usually modeling weaving and driver behavior with FHWA's CORridor SIMulation model is sufficient but since portions of this super-interchange required more than 6 lanes in each direction, a newer simulation model VISSIM was needed to determine if the lanes would be properly utilized throughout the projects life.

Estimating the Benefits of Access Management Treatments: Lessons Learned In Texas

Anna T. Griffin, E.I.T., William L. Eisele, Ph.D., P.E., and William E. Frawley, AICP,
Texas Transportation Institute

Abstract. As transportation planners and engineers seek innovative methods to reduce crashes, improve mobility, decrease automobile emissions, and preserve the operation of roadways in their jurisdiction, access management techniques are receiving renewed interest. This paper describes a project sponsored by the Texas Department of Transportation (TxDOT) in which the benefits of implementing access management techniques were estimated through the use of microsimulation and crash analysis.

In this project, the researchers developed an experimental design to collect data and perform sensitivity analysis of varying traffic conditions and access management treatments on three selected corridors in Texas. Theoretical corridors were also created to simulate access management impacts as well. The VISSIM software package was used to perform the analysis. The simulation was performed on the corridors by varying traffic volumes on the roadway and at driveway locations to identify the incremental benefit of access management treatments compared to a condition in which the treatments are not present. Performance measures such as travel time and delay were used. The installation of raised medians, signal spacing, driveway spacing were the primary access management treatments investigated in the study. The data collection process and methodology of creating a model to perform the simulations in VISSIM are discussed in the paper.

Crash analysis was also performed at four case study locations in Texas where a raised median was installed. The processes of collecting crash data and investigating the quality of the data as well as procedures for data reduction are discussed in this paper. Quality control procedures for data reduction that can be used in future projects are summarized in this paper. A before-and-after study was conducted on the crash data providing both summary statistics and statistical analysis to estimate the raised median impact in providing a statistically significant reduction in different types of crashes. This research is anticipated to be useful for planners, engineers, and other transportation professionals in communicating the benefit of access management treatments.

Ohio's Statewide Congestion Analysis Process

Greg Giaimo, *Ohio DOT*

No abstract available.

Louisiana State Transportation Plan

Dale Janik, P.E., *Wilbur Smith and Associates*

Abstract. The Louisiana Department of Transportation and Development (DOTD) has been working with a consultant team over a 2+ year period to update the state's 1996 Statewide Transportation Plan. This new effort builds upon the work in the 1996 Plan and incorporates several important components:

- Development of a Statewide Travel Demand Model to provide a sound technical basis for evaluating the attributes of complex, high cost "mega" projects.
- Incorporation of input from updated pavement and bridge management systems to articulate highway "needs" from a technical viewpoint.
- Strong Public Involvement Process, including interaction with eight transportation Advisory Councils to build transportation Plan recommendations from the "bottom up," incorporating public/private viewpoints as a basic tenet of the study.
- Development of stand-alone Rail and Aviation Plans to update aged information regarding these important modes.
- Bringing all modes to the fiscal "table" to ensure solid, long term financial stability for Louisiana transportation.
- Recognizing the need for consideration of both freight and passenger transportation considerations in long-term Louisiana planning.

The presentation summarizes the approach and results of the Plan.

Application of Highway Crash Frequency Prediction Model for Highway Transportation Planning

Hong Zhang, *Louisiana State University*

Abstract. Highway safety on two-lane highway has always been a big concern for traffic engineers since these highway facilities generally experience relatively low traffic volumes but high frequency of crashes. Annually, about one-third of total number of highway crashes occurs on two-lane highways in Louisiana. For this reason, various improvement projects on two-lane highways have been constantly undertaken in Louisiana. Using the crash frequency prediction model to estimate the safety benefit of two-lane highways' improvement projects provides key information to the process of highway transportation planning.

This presentation will introduce the results of such a study with the historical Louisiana highway crash records and the Interactive Highway Safety Design Model (IHSDM) developed by the FHWA. The model estimates the expected number of highway crashes as a function of ADT and length of the segment. To apply the model, we first calibrate the model parameters by using the actual crash frequencies on each segment from the past 11 years. The comparison between the expected number of crashes predicted by the model and the actual number of crashes are made based on which the further model stratifications are conducted. The analysis made at the disaggregated level reveals more accurate pictures on the cause of crashes. The results of this study can be used to estimate the safety impact of highway improvement projects proposed during planning process.

Rural two-lane highways account for about 83 percent of the state maintained highways but only 34 percent of vehicle miles traveled in Louisiana. Annually, about one-fourth of the total traffic accidents and half of the fatalities occur on these low volume highway facilities. The average fatality rate for rural two-lane highways is 2.87 per 100 million vehicle miles, which is higher than the state average of 1.87 per 100 million vehicle miles for all highway facilities. Therefore, safety on rural two-lane highways is a big concern for traffic engineers.

Estimating the safety performance provides key information for the evaluation of an improvement project. Several approaches have been used in the past: estimates from the historical accident data, before-and-after studies, and statistical regression models. However, each approach has its own weakness. The Crash Prediction Model, a component of Federal Highway Administrations Interactive Highway Safety Design Model (IHSDM), is a new approach that combines the advantages of past approaches (1). The model predicts the total expected accident frequency during a specified period of time as a function of traffic volumes, geometric design features, and traffic control features of roadway segments. The base model is based on a negative binomial regression analysis. The accident modification factors developed by an expert panel assure that the prediction is sensitive to the site-specific geometric design and traffic control features.

Proper calibration of the base model can make it adapted to local conditions. The use of site-specific historical accident data can also be used to improve the accuracy of the prediction.

The objective of this study is the calibration and application of a crash prediction model for rural two-lane highways in Louisiana. Calibration involves the calibration of the base model and the application of accident modification factors. Model application includes identifying high accident locations, predicting crash frequency on existing highways, establishing accident distribution, and estimating the safety impact of improvements to the segment. To identify high crash locations, the predicted accident frequency of a roadway segment was compared with the observed number of accidents over an 11-year evaluation period. To improve the accuracy of the prediction, the model-predicted accident frequency is combined with the site-specific accident history data.

Data

A 13-year (1988-2000) record of roadway segments and a 12-year (1989-2000) record of accidents in Louisiana were used in this study. Both databases were provided by the Louisiana Department of Transportation and Development through a project conducted at University of Louisiana at Lafayette. The segment database stores the information related to each roadway segment such as traffic volume, roadway geometric feature, yearly accident number and rate. The accident database contains the attributes of each accident including time, location, accident type, and severity, etc.

The total length of state-maintained rural two-lane highways in Louisiana is about 13,000 miles. There were 5,662 segments in the system in 1988 and 5,855 segments in 2000. Of these, 4746 segments kept the same start and end points throughout the evaluation period. These were selected for analysis in this study because the segments must keep the same if accidents statistics are to remain compatible from year to year. The total number of accidents and fatalities in the database for each year are listed in Table 1.

Table 1 - Number of Accidents and Fatalities in Louisiana by Year

Year	Accidents		Fatalities	
	all highways	2-lane rural highways	all highways	2-lane rural highways
1989	55,914	15,605	665	360
1990	79,863	18,105	642	337
1991	75,271	18,098	610	304
1992	75,665	16,218	624	318
1993	73,277	15,885	589	293
1994	81,897	16,806	564	286
1995	86,047	17,382	585	312
1996	87,137	17,764	606	302
1997	91,715	19,019	639	309
1998	89,203	17,529	735	318
1999	77,590	17,634	616	308
2000	77,361	18,687	658	342

The main attributes in the roadway segment database are:

- year
- segment number
- logmile_from (start point)
- logmile_to (end point)
- length of the roadway section
- highway functional class
- ADT
- shoulder type
- shoulder width
- pavement type
- pavement width
- annual number of accidents
- annual accident rate

The main attributes in the accident database are:

- year
- date
- hour
- weekday
- parish
- city
- highway number
- mile post
- accident type
- collision type
- severity
- vehicle speed
- road condition
- surface condition
- violation type
- vehicle condition
- driver's condition

Model Development

There are two separate accident prediction algorithms in the IHSDM model. They are two prediction algorithms for roadway segments and at-grade intersections. This paper is only focused on roadway segments because of the lack of information for intersections. The model development includes establishing the base model application, applying the calibration procedure, and adjusting the base model with accident modification factors (AMFs). An Empirical Bayes (EB) procedure was used to combine the model-predicted crash frequency with the site-specific accident history data to improve the accuracy of the prediction.

Base Model

The base model was developed in the original FHWA study using a negative binomial regression model. The base model estimates the magnitude of accident frequency for roadway segments under “normal” conditions, with the following specifications:

Lane width	12 ft
Shoulder width	6ft
Roadside hazard rating	3
Driveway density	5 driveways per mile
Horizontal curvature	None
Vertical curvature	None
Grade	Level

Under these conditions, the base model for roadway segments has been estimated as:

$$N_{br} = (ADT)(L)(365)(10^{-6}) \exp(-0.4865)$$

where,

N_{br} = base model predicted number of total accidents per year on a particular roadway segment;

ADT = average daily traffic volume (veh/day) on roadway segment;

L = length of roadway segment (mi).

Calibration

The base model produces the estimates of average accidents under normal conditions. The calibration procedure aims to adjust the differences among states caused by factors such as climate, driver population, and accident reporting threshold. It is implemented by determining the value of a calibration factor, which is applied as a multiplication factor to the base model. It is the ratio of observed total number of accidents to the model-predicted total number of accidents for all roadway segments during a certain period of time (normally 2 to 3 years). Recalibration needs to be conducted every 2 or 3 years. With the calibration factor, the base model takes the following form:

$$N_{rs} = N_{br} C_r$$

where,

N_{rs} = predicted number of total accidents per year on a particular roadway segment;

C_r = calibration factor for roadway segments.

Calibration factors of each year are listed in Table2.

Table 2 - Calibration Factors for Rural two-lane Highways in Louisiana (C_r) (1988-2000)

Year	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Calibration Factor (C_r)	1.95	1.95	1.95	1.98	1.98	1.98	1.77	1.77	1.77	1.78	1.78	1.68	1.68

Accident Modification Factors

The accident modification factors (AMFs) are used in the accident prediction algorithm to represent the effects on safety of specific geometric design and traffic control features. These factors adjust the default value in the base model to the individual roadway segment.

Only two modification factors can be applied in this application because of the lack of data. AMF_1 is used to adjust for lane width and AMF_2 for shoulder type and width. These factors were quantified by the Expert Panel.

After adding these two factors, the base model is:

$$N_{rs} = N_{br} C_r AMF_1 AMF_2$$

where,

AMF_1 = accident modification factor for lane width;

AMF_2 = accident modification factor for shoulder type and width.

Empirical Bayes Procedure

Considering site-specific accident history is very helpful in improving the accuracy of prediction on individual links. The Empirical Bayes (EB) procedure combines the model-predicted accident frequency with the site-specific accident history by using the weighted average of the two as the final prediction:

$$E_p = W(N_{rs}) + (1-W)O_b$$

where,

E_p = Expected accident frequency based on a weighted average of N_{rs} and O_b ;

N_{rs} = number of accidents predicted by the accident prediction algorithm during a specified period of time;

W = weight to be placed on the accident frequency predicted by the accident prediction algorithm;

O_b = number of accidents observed during a specified period of time.

The weight factor W is determined as:

$$W = \frac{1}{1 + k(N_{rs})}$$

where,

k = overdispersion parameter of the relevant base model of the accident prediction algorithm; $k = 0.31$ for roadway segments.

Model Application

Identifying high accident locations

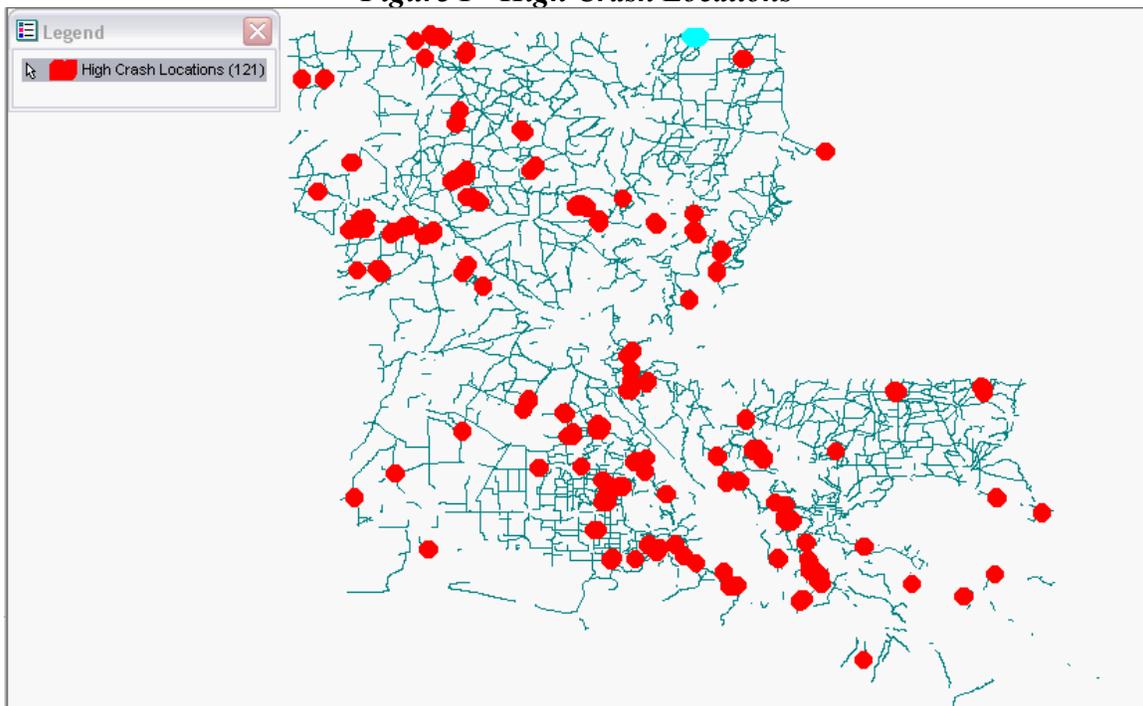
Identifying the high accident locations is one of the most important applications of the model. There are several ways to distinguish high accident locations. The total number of

accidents is not a good indicator because it ignores the traffic volume. Accident rate is a better measure since it considers the volume. However, it does not reflect the roadway geometric design features, which may be unavoidable features of the segment in question. Regression model estimates are based on statistical correlations between roadway characteristics and number of accidents that do not necessarily represent cause-and-effect relationships. The crash prediction model in IHSDM incorporates the traffic volume and the roadway geometric design features and therefore provides a better solution to determine high accident locations (1).

The model-predicted total number of accidents N_{rs} for the 11-year period on each segment was compared to the observed total number of accidents O_b during the same period. Segments with the percent error ($\frac{N_{rs} - O_b}{O_b} \times 100\%$) above 2 standard deviations were considered as high accident locations (2). In identifying the high accident locations, the EB procedure was not used. Accident rate was employed to observe the similarity of the results from the two methods.

Of the 4,746 roadway segments, 121 considered in the analysis were identified as locations with unusually high accident frequency. It accounts for 2.5 percent of the total rural two-lane segments in this study. Accident rate for these segments was 8.78 accidents per million vehicle miles, which is 6.4 times higher than the average rate of 1.37 for all rural two-lane highway segments. This number suggests that the identification of high accident segments is reliable. The model predicted more accidents than those observed on 64 percent of the segments. The locations of the high accident segments are mapped in Figure 1. These sites are fairly evenly distributed throughout the state.

Figure 1 - High Crash Locations

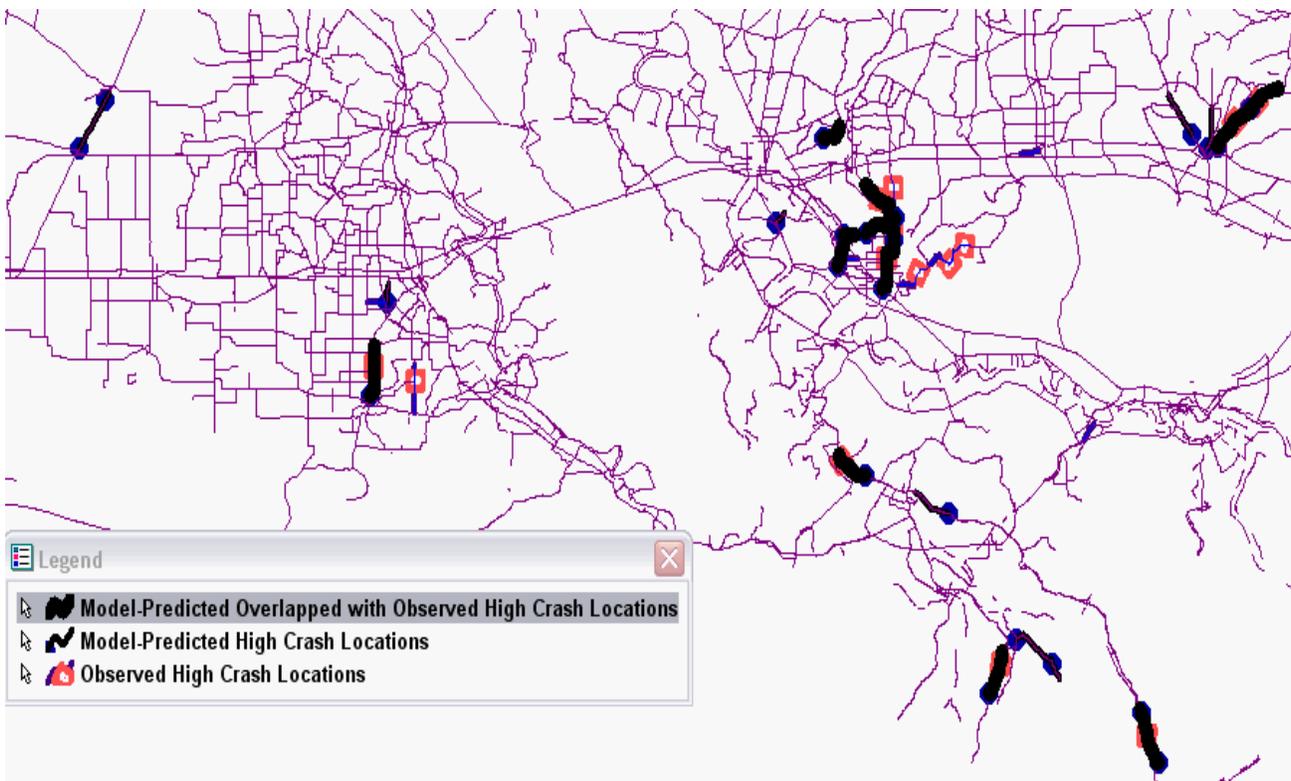


Predicting the safety performance of existing highways

For the existing highway network, being able to predict the safety performance in the future is important for planning and management. In this study, prediction of crash frequency was applied to year 1999, a year for which observed values are available. The EB procedure was used to improve the accuracy of the prediction. The observed number of accidents was used to assess the accuracy prediction.

The predicted crash frequency for year 1999 is close to the actual value. At the aggregate level, the model-predicted total number of accidents for all rural two-lane highway segments in this study was 9328, while the observed value was 9505. At the disaggregate level, 68 percent of total segments have an absolute difference between predicted accident number and observed accident number of less than 2. In addition, 11 segments of the model's predicted top 20 segments with the highest crash frequency overlapped with the observed top 20. They were clustered into 7 locations as shown in Figure 2.

Figure 2 - Model-Predicted and Observed High Crash Locations



Establishing Accident Severity and Accident Type Distributions

The Crash Prediction Model provides a default distribution of accident type and severity level. The distributions can be used to predict the proportion of a certain type of accident or a particular level of severity in the total number of accidents; therefore, the cost of the

accidents could be estimated accordingly. Based on the data in Louisiana for years 1999 and 2000, the distributions of single-vehicle accident type, multi-vehicle collision type, and accident severity level were calibrated. The results are shown in Table 3 and Table 4.

From the accident distribution, it is obvious that rural two-lane highways in Louisiana experienced less single-vehicle accidents but more multi-vehicle accidents than model default value. Of all single-vehicle accidents, the proportion of ‘collision with animals’ is 3.7 percent, which is much smaller than 30.9 percent in the model. There were higher proportions of angle, left-turn, and rear-end collisions in the multi-vehicle accidents in Louisiana.

The distribution of accident severity level reveals that 1.7 percent of all accidents on the rural two-lane highways in Louisiana were fatal, which is higher than 1.3 percent provided by the model. The proportion of total injury accidents was 42.2 percent, which was 10.1 percent higher than model default value of 32.1 percent.

Table 3 - Distribution of Accident Type and Manner of Collision

Accident type and manner of collision	Percentage of total accident	
	IHSDM	Louisiana
SINGLE-VEHICLE ACCIDENTS		
Collision with animal	30.9	3.7
Collision with bicycle	0.3	0.0
Collision with parked vehicle	0.7	0.0
Collision with pedestrian	0.5	0.4
Overtaken	2.3	1.0
Ran off road	28.1	22.7
Other single-vehicle accident	3.6	12.4
Total single-vehicle accidents	66.3	40.2
MULTI-VEHICLE ACCIDENTS		
Angle collision	3.9	8.7
Head-on collision	1.9	1.7
Left-turn collision	4.2	7.8
Right-turn collision	0.6	1.2
Rear-end collision	13.9	22.7
Sideswipe opposite-direction collision	2.4	2.5
Sideswipe same-direction collision	2.6	2.8
Other multi-vehicle collision	4.1	12.4
Total multi-vehicle accidents	33.7	59.8
TOTAL ACCIDENTS		
	100	100.0

Table 4 - Distribution for Accident Severity Level

Accident severity level	Percentage of total accident	
	IHSDM	Louisiana
Fatal	1.3	1.7
Incapacitating injury	5.4	1.5
Nonincapacitating injury	10.9	13.0
Possible injury	14.5	26.0
Total fatal plus injury	32.1	42.2
Property damage only	67.9	57.8
TOTAL	100	100.0

Estimating the safety benefit of roadway improvement project

The safety benefit of roadway improvement projects such as widening the lane width and shoulder width can be estimated by using the model. For example, 36 accidents occurred on segment 077-02 (logmile between 1 and 4.6) in 1998. For this roadway segment, the lane width was 10 feet and the shoulder width was 3 feet. The total number of accidents predicted in 1999 by the model was 35 if the geometric features of the roadway were left unchanged. However, it is estimated that this number would decrease by 5 per year by widening the lane width from 10 to 12 feet and shoulder width from 3 to 6 feet.

The ratio of the safety benefit to the construction cost for the next 20 years could be calculated as the following: The total number of accidents will be decreased by 5 per year or 100 for the 20-year period. According to the severity distribution in Louisiana, these would be made up of 2 fatal accidents, 2 incapacitating injury accidents, 13 non-incapacitating injury accidents, 26 possible injury accidents, and 57 property damage only accidents. The safety benefit of this improvement project could be estimated by adding the accident costs of each severity level together. According to the information provided by Federal Highway Administration (1994), the following accident costs were suggested:

- \$2,600,000 for a fatal accident,
- \$180,000 for an incapacitating injury accident,
- \$36,000 for a non-incapacitating injury accident,
- \$19,000 for a possible injury accident,
- \$2,000 for a property damage only accident.

The approximate estimate is \$6.6 million. For the construction cost, we assume that the current cost of upgrading (widening) and the cost of an overlay 10 years after the construction. The upgrading cost for 3.6 miles is estimated as \$0.72 million, and the overlay cost is \$0.27 million. Based on this information, the B/C (benefit / cost) ratio is computed as 6.7. This number indicates that this improvement project is very beneficial.

This analysis could also be applied to select the alternative geometric design features of the proposed highways.

Conclusions

The objective of this study was the application of the Crash Prediction Model for rural two-lane highways in Louisiana. The model combines the regression analysis, historical accident data, and expert judgment to make more accurate estimate of roadway safety performance. It can be applied to identify high crash locations, predict the crash frequency of existing highways, and estimate the safety benefit of improvement project or proposed highway designs.

The model is more useful in identifying the high crash locations than accident number and rate because it considers both traffic volume and roadway geometric design features. It was identified by the model that 121 rural two-lane roadway segments are high crash locations in Louisiana. The unusually high accident rate of these segments verified the reliability of the results. The use of site-specific accident history data makes the prediction more accurate. The comparison between model-predicted and observed accident frequency for each roadway segment in 1999 indicated that the prediction is close to the actual number. The distribution of accident type and severity level could be used to estimate the safety benefit of highway improvement projects or alternative geometric design features of proposed highways.

The drawback of this model is that more data such as detailed geometric design features of the roadway and historical accident data are required, and thus more effort is demanded to implement it. In addition, the interaction among roadway geometric design features is neglected by the model. The expert panels that developed the AMFs (accident modification factors) indicated this point but the difficulty on how to quantify the interactions remains unsolved. Hence, more attention needs to be given to this question in the future research.

The data limitation is crucial to the model application. Although many geometric design features are required by the model to apply the AMFs, only lane width, shoulder type and width are available. Also, the crash prediction model could not be applied to intersections in this study because the information of ADT for both roadway directions was not available. Therefore, detailed information is highly expected in the future to improve the model application.

Acknowledgement

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TRANSIMS GEN2 Model Specifications for the Portland Test Case

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Abstract. Considerable resources and creative thought have been invested in the development of TRANSIMS. TRANSIMS represents a bold new paradigm in the structure and formulation of travel demand models. Its underlying foundation rests upon the employment of simulation techniques to describe and quantify travel demand behavior and resulting patterns -- represented in both time and space. The Portland case study, because it represents the first real-world implementation of TRANSIMS, will be central to the ultimate success and acceptance of TRANSIMS as a valuable tool for transportation planning and design.

The Portland test case represents the examination of TRANSIMS within the context of model application to real-world scenarios. The first real test of TRANSIMS will be its ability to achieve calibration/validation results for 1996 that are, at a minimum, comparable to standards typically evidenced in classical four-step sequential model systems. The work program also envisions extensive sensitivity tests and evaluation of the model's performance in the context of a long-range Regional Transportation Plan and/or Major Corridor Study. This evaluation will largely focus on a series of performance measures that compare and contrast the results with real-world experience.

This presentation focuses on the TRANSIMS model specifications for the development and implementation of a second generation (GEN2) modeling system for Portland. Each TRANSIMS component from the population synthesizer to the router and micro-simulator is presented and discussed.

Using Traditional Model Data for Microsimulation and Emission Estimates

David B. Roden, P.E., *AECOM Consulting Transportation Group*

Abstract. AECOM Consulting is working with FHWA and EPA to identify ways to combine the capabilities of TRANSIMS and MOBILE6 to improve the current state of the practice in emission estimates and air quality conformity analysis in urban areas. In order to facilitate comparisons between the microsimulation approach and current practice, AECOM Consulting will base the microsimulation analysis on networks and trip tables extracted from traditional travel demand forecasting models. The project will convert the EMME/2 networks and trip tables for Portland, Oregon to TRANSIMS. The converted regional data will then be used for route planning, microsimulation, and emission estimation within TRANSIMS. A comparison will be made between the traditional regional model emission estimates and the TRANSIMS emission estimates. This will help potential implementing agencies understand the costs and benefits of using a microsimulation approach for air quality analysis in their region.

This presentation will describe the conversion process from a traditional regional model to TRANSIMS. It will document the microsimulation results and compare these results to the traditional regional model. The presentation will also provide a summary of the emission estimates generated by TRANSIMS. It will also describe a variety of additional tests and comparisons that are being investigated for FHWA and EPA.

A Microscopic Traffic Simulation Model of West Midtown Manhattan

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Abstract. This work was performed as part of the 11th Avenue Viaduct Rehabilitation Project for the New York City Department of Transportation (NYCDOT), by Urbitran Associate's Inc. in cooperation with Daniel Frankfurt, PC. The contents of this paper reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of NYCDOT, Urbitran Associates, Inc., or Daniel Frankfurt, PC. This paper and any of its contents reflect preliminary results which are subject to change and do not represent an official standard, specification, or regulation.

Due to the planned rehabilitation of approximately twenty (20) NYCDOT bridges crossing AMTRAK rail lines located in West Midtown Manhattan, a comprehensive traffic study is currently underway to evaluate the traffic impacts of proposed Maintenance and Protection of Traffic (MPT) schemes. Given that this area is notoriously congested during peak hours, any proposed street closure or restriction could have significant and far reaching consequences. Therefore, it is necessary to be able to reasonably predict the changes in traffic patterns and routes due to closed or restricted streets. Based on Urbitran Associates, Inc. (Urbitran) modeling expertise and local knowledge it was determined that a microscopic simulation model using a dynamic-stochastic route assignment method would be best suited for comparing the operational impact of various MPT schemes.

The scope of this microsimulation model was determined to require:

- Two (2) Weekday Peak Traffic Time Periods (6:00-10:00 AM & 3:00-7:00 PM)
- Multiple Vehicle Types (cars, trucks, and buses)
- All Streets / Intersections Modeled in the Study Area
- Dynamic-Stochastic Route Assignment

Available micro-simulation packages were evaluated based on the above needs. *Quadstone Ltd. Paramics (Paramics)* was selected by Urbitran as the most suitable software package available for this particular project. Due to the size and complexity of the proposed study area, as well as the congested nature of a dense urban grid street system, the project posed a number of significant challenges. This paper will discuss the development of the 'Base Conditions' microsimulation model of West Midtown Manhattan.

This will include the selection of the study area, a summary of the data collection program undertaken, the development of the microsimulation model, model calibration, model validation, and finally some of the particular challenges encountered during the project.

Selection of the Study Area

The study area is composed of the ‘Primary Study Area’ - where the direct effects of MPT schemes are expected - and the ‘Secondary Study Area’ - where the travel patterns from and to the primary study must be considered to accurately represent traffic conditions. The extent of the study area is generally a balance between the project objectives, the potential extent of the alternatives to be evaluated, jurisdictional boundaries and the available monetary resources. Based on these general guidelines, the study areas are as follows (**see Figure 1**):

- The primary study area limits are 57th Street to the north, 30th Street to the south, 8th Avenue to the east and the Hudson River to the west.
- The secondary study area extends to 59th Street to the north, 6th Avenue to the east, and to 23rd Street to the south.

This includes several significant locations such as; Columbus Circle, Times Square, the Lincoln Tunnel, and the Port Authority Bus Terminal in a seven (7) by forty (40) block area of highly congested urban streets.

Data Collection

A comprehensive data collection plan was undertaken to support the development of various MPT schemes, as well as the calibration and validation of the microsimulation model. Towards this objective, available traffic data was compiled and reviewed from a number of sources, including but not limited to, the New York City Department of Transportation (NYCDOT), NYC Department of City Planning (NYCDCP), and New York Metropolitan Transportation Council (NYMTC).

Traffic Counts

In addition to traffic data from secondary sources, traffic data was collected in both the primary and secondary study areas. This included Automatic Traffic Recorder (ATR) counts, manual Turning Movement Counts (TMC), vehicle classification counts, and counts at special generator sites. The collected traffic counts can be summarized as follows (**see Figure 1**):

- Approximately thirty-four (34) TMC locations
- Approximately one-hundred-and-sixty-five (165) ATR locations
- ‘Special Generator’ counts at significant individual facilities
- Additional Data requested from Fed-Ex, UPS, and USPS

Roadway Inventory

In addition to the traffic data program, a roadway inventory was performed that included the following:

- Configuration of each intersection and its approach
- Signal timing and offset information

- Parking Regulations (regulations for each curb at the intersection)
- Bus stop locations, Bus lanes and Bus turn restrictions and priorities

Travel Time Surveys

A travel time survey was performed for the following corridors, during the morning (6-10 a.m.) and evening (3-7 p.m.) peak periods:

- 11th Avenue from 23rd Street to 59th Street
- 10th Avenue from 23rd Street to 59th Street

Development of the PARAMICS Microsimulation Model

Development of the *Paramics* microsimulation model can be broken down into two main tasks:

- A topographical representation of the simulation network
- A representation of the demand for the simulation network (Trip Table).

While the development of each component is reasonably independent of the other, each often influences the development of the other. They are discussed in more detail below:

Topographical Representation of the Simulation Network

In order to accurately represent traffic conditions in the study area all streets in both the primary and secondary study areas were coded in *Paramics*. To achieve this objective, a skeleton network was developed based on the NYCDOP 'LION' file and it was refined using available data sources

The refinement process included the use of field collected data and site specific sources, such as: traffic or construction plans were used when available. In addition, high-quality aerial imagery (1m resolution) was found to be particularly useful during network coding. *Paramics* is capable of importing these images directly to the background of the microsimulation model, where the images can be essentially traced and compared to the model (**see Figure 2**).

Two (2) peak time periods were modeled. For each, peak traffic period a separate microsimulation network was developed, to incorporate potential operational differences between morning and evening periods, such as the reversible lanes for the Lincoln Tunnel

The network (**see Figure 3**) was initially tested using a very light estimated traffic load. This allowed any blatant errors or omissions to be identified and fixed before the actual calibration process began. Despite this effort, it was found that continuous topographical modifications and error-checking were required throughout the development of the model in order to most accurately represent observed conditions.

Development of the Trip Table

For this project, secondary sources were used as the basis for the O-D trip table. The sources that could provide this information were the Route 9A Reconstruction Project (R9A) and the New York Transportation Council (NYMTC) Interim Analysis Method (IAM) of the Transportation Models and Data Initiative project.

The R9A trip table was the product of a sub-regional travel demand model including origin-destination survey data, and its zone system was used where possible for the West Midtown Manhattan microsimulation model. A one-hundred-and-seventy-nine (179) zone trip table was developed, including one-hundred-and-twenty-four (124) internal zones and fifty-five (55) external entry / exit zones.

It became apparent that some of the traffic patterns reflected in the trip table did not correlate with the traffic patterns emerging from the traffic counts compiled for the study area. This could be attributed to the fact that the R9A corridor was under construction when the data was collected and that the R9A trip table reflected travel patterns from the late 1980's. For such cases, matrix estimation packages could be used to adjust the trip table based on observed counts. These packages are generally tied to specific planning transportation packages and are not generally available for microsimulation models, such as *Paramics*.

Loop Program

Urbitrans developed a matrix estimation program (called "LOOP") specific to the *Paramics* file structures, data input and routing algorithms to allow the validation of the microsimulation model to within acceptable differences between observed and modeled traffic volumes. LOOP compares the observed and simulated link volumes and calculates the differences. The O-D table is then adjusted proportionately, according to which O-D trips passed through the particular link. Since a stochastic-dynamic route assignment method was used, the number and variations of routes between each O-D pair varies as time passes during each simulation run. In addition, each time the O-D table changes it is likely that the choice of routes between each O-D pair will also change. Therefore, adjustments were made gradually and multiple iterations were performed.

O-D table adjustments were made first on a screenline basis, ensuring that all trips crossing the screenline are captured during the adjustment process. Several screenlines established during data collection were used including; East-West screenlines between 33rd and 34th Street, 41st and 42nd Street, as well as North-South screenlines between 6th and 7th Avenue, 8th and 9th Avenue, and 10th and 11th Avenue.

While the LOOP program was found to be particularly useful in dealing with the size and complexity of this trip table, it was often necessary to make manual trip table adjustments. When traffic patterns and proportions were determined to be inaccurate adjustments were made directly to the trip table as necessary.

Temporal Distribution of Traffic

Since the West Midtown Manhattan model included both a morning (AM) and an afternoon (PM) peak period network, it was necessary to develop two distinct O-D trip tables. In addition, to account for the traffic variations over each period, the AM and PM trip tables were expanded to four (4) hourly trip tables for each peak period according to the available collected traffic data. This allowed for sufficient traffic to be loaded on the network before each period's peak hour, when analysis would be done, and dissipated after the peak hour. In addition, *Paramics* allows the use of demand 'profiles' to further represent temporal

differences in traffic from individual demand zones, in increments as low as every five (5) minutes. For example, demand ‘profiles’ were used to represent increasing and dissipating demand through significant network entry points, such as; the Lincoln Tunnel, according to the available data

Calibration

Calibration is the process of adjusting the various parameters and factors in order to most accurately represent observed conditions. In the case of the West Midtown Manhattan microsimulation model, where driver aggressiveness and network complexity are higher than normal, this is a vital component of the model’s development. *Paramics* includes multiple parameters and factors which can be adjusted, and have differing effects on the microsimulation’s behavior with respect to route choice, driver behavior, throughput capacity etc...

Route Choice Parameters

There are several factors which affect the choice of routes between O-D pairs. The most basic of these is the ‘Generalized Cost Equation’¹. The calculation of the route ‘cost’ is described below.

$$\text{Cost} = a * (\text{Travel Time}) + b * (\text{Distance}) + c * (\text{Price}/\$)$$

Where: a = time coefficient in minutes per minute (default = 1.0)
 b = distance coefficient in minutes per mile (default = 0.0)
 c = toll coefficient in minutes per monetary cost (default = 0.0)

For this project the following generalized cost is used:

$$\text{Cost} = 1.0 * (\text{Travel Time}) + 2.5 * (\text{Distance}) + 0.0 * (\text{Price}/\$)$$

In general, simulated drivers will choose the route with the lowest cost. However, in reality it is unlikely that all drivers will choose the same route for a particular O/D trip, especially in a congested grid system where many routes appear to be very similar. The stochastic component of the route choice accounts for this random variability and allows different vehicles to choose different routes between each O/D pair.

Paramics uses a factor called ‘perturbation’ to describe this variability for each vehicle type or class allowing different drivers to perceive slightly different route costs. For this project, percent perturbations of between 5-10 % were used in most cases.

In order to represent the dynamic nature of route choice observed in Midtown Manhattan, a ‘feedback’ of one (1) minute was used. This means that all cost calculations are further modified at one (1) minute time intervals to accommodate delays due to congestion. Modeled drivers designated as ‘familiar’ receive this updated information and are able to alter their route mid-trip. Finally, the perceived generalized costs could be manually adjusted on a link

¹ Quadstone Ltd. *PARAMICS ModellerV3.0 UserGuide and Reference Manual*, Edinburgh, UK, February 2000

or group of links basis, using link cost factors, in order to reduce unrealistic or illogical route choices.

Driver Behavior

Paramics uses two main factors to estimate driver behavior. These are Headway (H), expressed in seconds, and Reaction Time (R), also expressed in seconds. Values of 0.5 seconds and 0.15 seconds were used for the AM and PM networks, to account for the extremely aggressive and fluid nature of Midtown Manhattan drivers these values were required. It should be noted that other studies² utilizing *Paramics* have indicated the use of low headway values to accommodate congested conditions. The low headway factor allowed sufficient throughput capacity to be simulated, as was observed with actual traffic counts. The reaction time was lowered in conjunction with the headway in order to allow sufficient lane changing and gap acceptance to occur in the congested conditions of Midtown Manhattan.

Validation

Before the *Paramics* model could be used to evaluate alternatives, model accuracy had to be verified to ensure that the model realistically represented traffic conditions in the study area.

The validation process involved two main components. First, the average variation in the percent difference between the observed and modeled street traffic volumes was calculated to determine how closely model assumptions replicated observed traffic volumes. Based on experience it is assumed that model validation is achieved when the average variation in the percent difference for the AM and PM peak hours in the observed and modeled volumes is within the following target values for four separate link volume groups:

<u>Volume Group (vph)</u>	<u>Validation</u>
250-500	50 %
500-1000	30 %
1000-2000	25 %
> 2000	15 %

As demonstrated in **Tables 1 and 2**, the average variation for various volumes categories is well within the acceptable levels.

Table 1 : AM Percent Deviation (draft) 8:30-9:30 AM

Volume Group (vph)	Avg. Percent Deviation	Observed Volume (veh)	Modeled Volume (veh)	Number of Links	Average Observed Volume	Average Modeled Volume
250-500	53.1	17315	19666	48	361	410
500-1000	27.8	18695	16888	29	645	582
1000-2000	21.8	27835	25832	17	1637	1520
> 2000	11.9	12775	13088	5	2555	2618

² *Genetic Algorithm*, National University of Singapore, TRB 01-2399. Washington D.C. January 2001

Table 2 : PM Percent Deviation (draft) 5:00-6:00 PM

Volume Group (vph)	Avg. Percent Deviation	Observed Volume (veh)	Modeled Volume (veh)	Number of Links	Average Observed Volume	Average Modeled Volume
250-500	35.1	25649	24203	67	383	361
500-1000	29.1	46597	43955	70	666	628
1000-2000	22.4	57563	52563	38	1515	1383
> 2000	14.3	47336	46913	20	2367	2346

The second component in the validation process was to compare modeled travel times to observed travel times along the 11th and 10th Avenues. Observed and model travel times compare favorably, given the expected variation in Manhattan travel conditions.

Significant Challenges & Concluding Remarks

In summary, the completion of a calibrated and validated Base Condition Microsimulation model was found to be challenging. In particular, the development of a reasonable O-D trip table was a significant undertaking. The completion of a comprehensive data collection program, the use of any available secondary O-D sources, and the development of a custom *Paramics* demand estimation program (LOOP) were found to be crucial to the successful completion of this task.

The calibration of the various *Paramics* factors and parameters was also found to be vital to meeting the validation criteria. Due to the relative scarcity of information and applicable examples of similar microsimulation projects, this was also found to be a time consuming task. In addition, due to the effect of these factors on the performance and behavior of the model, the need to continuously move between the development of the trip table and the calibration process was particularly demanding. It was found that significant experimentation was required to achieve the desired results.

Due to the complexity and highly congested nature of the project area, the microsimulation model was found to be extremely sensitive to seemingly minor changes. Significant time and modeling creativity was required to solve particular problems and unique situations. Urbitran worked closely with the software developer (Quadstone Ltd) to troubleshoot particular issues, and in some cases modify the software package itself to represent observed conditions

While the development of the West Midtown Manhattan microsimulation model presented significant challenges, Urbitran was able to successfully complete the calibration and validation of the Base Condition model. The experience gained has already proven to be valuable in the application of other similarly complex microsimulation models. In conclusion, Urbitran has found microsimulation to be a viable and effective tool, even in the seemingly impossible-to-model conditions of Midtown Manhattan.

Figure 1: Study Area and Data Collection Locations

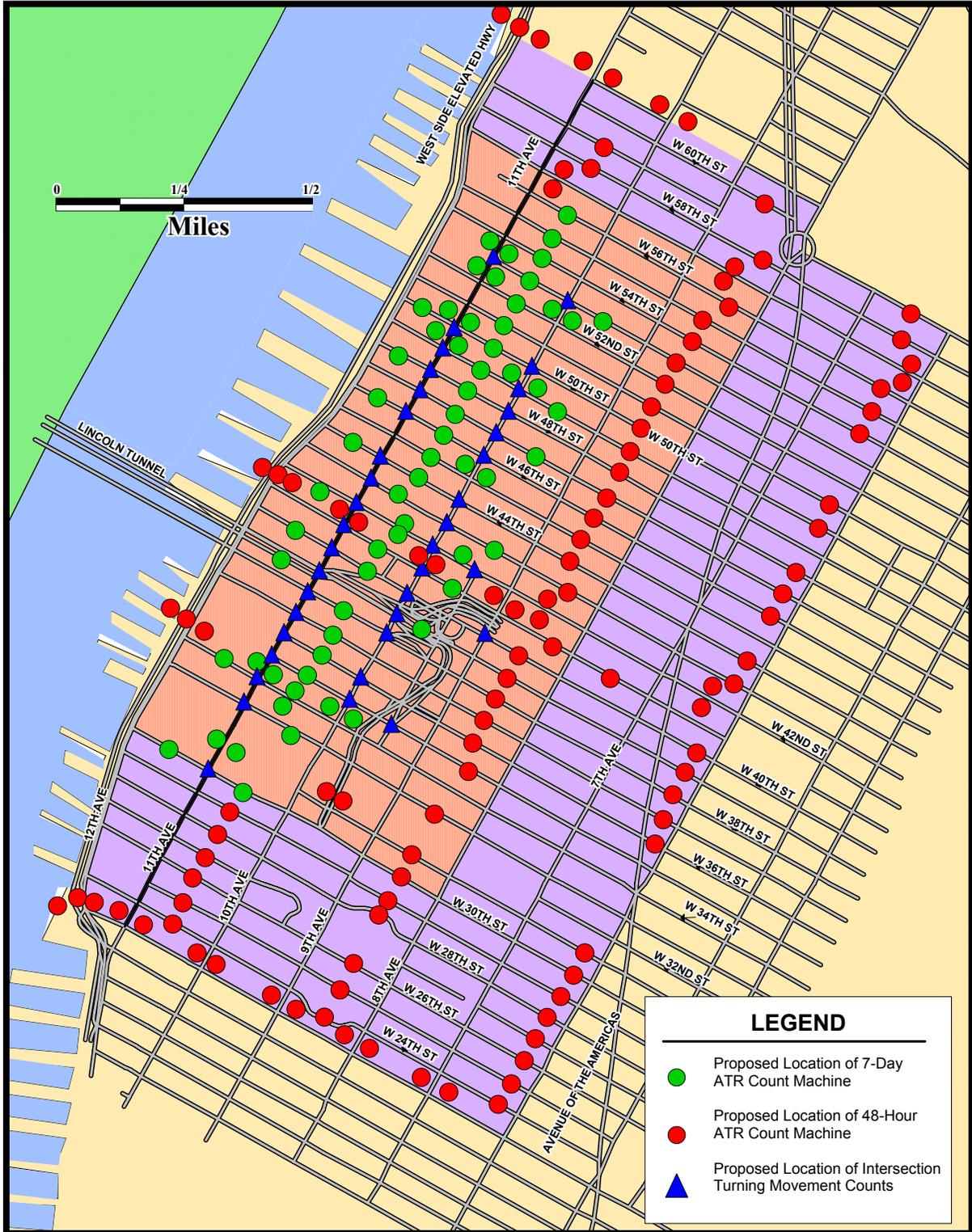


Figure 2: Example of Paramics Microsimulation and Aerial Imagery



Figure 3: Screenshot of West Midtown Manhattan Paramics Microsimulation Model



Miami Downtown Transportation Master Plan (MDTMP) Study

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Abstract. Under a consultant contract with the Miami-Dade Metropolitan Planning Organization (MPO), the Miami Downtown Transportation Master Plan (MDTMP) project micro-simulation model has been developed by Leftwich Consulting Engineers, Inc. (LCE), working as a sub-consultant to David Plummer and Associates (DPA), using the PARAMICS modeling suite. This document provides a summary of the validation efforts for the project. There are two related but separate components in the simulation for the Miami Downtown Transportation Master Plan project. The Validation component replicates existing conditions while the Future Analysis forecasts travel based on different land use scenarios for the study area. Both components use a macro-simulation model (FSUTMS) for the large scale travel patterns, and a micro-simulation model (PARAMICS) for a more detailed scale of movements in the study area. Three different and distinct time periods are being analyzed to replicate morning, midday, and afternoon peak hour conditions. The midday peak includes the influence of three separate draw bridge openings/closings due to vessels using the Miami River, which creates additional burden on the already congested roadway network.

The project study area has three distinct sub-areas. These are the Brickell, Downtown Core and Omni areas. The area included in the model covers all roadways east of I-95, north of South 15th Road, west of Biscayne Bay, and south of North 20th Street. The final model network of the downtown Miami area has 481 junctions; 361 major intersections; 140 signalized intersections; 380 zones; Vehicles, Trucks, Buses, Light Rail Transit, and People Mover modes; and three time periods (AM, MD, PM). After an extensive and comprehensive worldwide analysis of micro-simulation packages, the PARAMICS software was chosen as the analytical tool for the simulation and analysis of travel patterns within the study area. The PARAMICS micro-simulation software required the development of Sectors (large areas with similar characteristics related to land use), Zones (smaller areas), Car parks (parking areas within each zone). For this model, the Sectors coincide with the Miami-Dade Urban Area Transportation Study (MUATS) FSUTMS-based model Traffic Analysis Zones (TAZs). A one-to-one correspondence was utilized. The Zones are comprised of external and internal areas that represent locations which can be the origin or destination of trips.

The development of the model network provided several challenges due to the size and complexity of downtown Miami. A CAD drawing was used to code the roadways, then an aerial photograph was used to match roadway and intersection locations. The network coding was performed as follows: built roadway network streets by direction, added stop bars, added roadway categories; added intersection junctions and turn bays; added parking garage entrances, exits, and capacities (car parks); added signal phasing and offsets, signal coordination and timings were provided by the Miami-Dade County Public Works Department for each of the time periods (this includes offset times for synchronization of signals in the roadway grid system that predominates in the downtown area); coded in turn bays and restricted turns where necessary; added external and internal Zones and matched to Sectors; coded in transit routes and stops for Metrorail, Metromover, and Metrobus (30+ routes).

The MDTMP project micro-simulation model is one of the largest networks in the world. Using the PARAMICS micro-simulation software was beneficial; it is a suite of high performance software tools used to model the movement and behavior of individual vehicles on the roadways in the project study area. The ease and efficiency of the network editor has allowed LCE to concentrate on accuracy while completing the network coding. Most importantly, the production of the MDTMP model is the foundation of future year analysis models of the downtown area.

Bridging the Data Gap between Travel Demand Models and Micro-Simulation Analyses with a Spreadsheet-Based Approach

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Abstract. The California Department of Transportation (Caltrans) has undertaken a Corridor Study of Routes I-5/I-205/I-580 – the main commuter and commerce route connecting Central Valley workers to jobs in the Silicon Valley and San Francisco Bay Area's East Bay. Traffic through the corridor is projected to grow rapidly, with commensurate decay in freeway operating conditions.

A spreadsheet-based model was developed to post-process regional travel demand model data in a streamlined manner, and to develop detailed information needed for micro-simulation analysis.

The spreadsheet model uses current and future travel demand model projections in conjunction with hourly ramp counts over an entire weekday throughout the study area. A key feature of the model is a peak spreading component that limits travel demand to available capacity. Excess traffic is moved to peak shoulder hours to maintain overall daily volumes. This improves upon the travel demand model output, which examines only single AM and PM peak hours.

Another feature of the spreadsheet model is that it provides data ready for a micro-simulation application. The micro-simulation analysis is then improved because it uses demand model projections – with areas of high and low growth – rather than a single growth rate projection.

Due to Corridor Study constraints, micro-simulation can only be conducted on a limited basis. For the full set of alternatives, performance measures from the spreadsheet model will be used.

Spreadsheet model performance measures, summarized for each hour and on a daily basis, include vehicle hours of travel and delay, average speeds, travel times and volume-to-capacity ratios. Because the model spreads excess demand to the peak shoulders, a key measure is the length of length of peak period congestion.

The spreadsheet model can easily be adapted to a number of corridor study applications, and provides useful performance measures for comparing one alternative scenario against another. In situations where resources are limited, the spreadsheet model can provide the final analysis needed for screening alternatives. In other situations, the spreadsheet model provides the needed detailed travel data needed for a micro-simulation analysis.

A Multidisciplinary Approach to Feeder Bus Planning

Katharine Eagan and Curvie Hawkins, Jr., *Dallas Area Rapid Transit*

Abstract. Dallas Area Rapid Transit expanded its highly successful light rail system by opening fourteen new stations on two lines within a fifteen-month period. These openings were accompanied by significant changes to the bus system. Those bus route changes occurred on four separate dates over a fifteen-month period.

The development of detailed plans for these service changes presented a challenge to the staff involved as they balanced other responsibilities with the demands of service redesign and tight schedules for project completion. A team approach was developed for undertaking the feeder route planning process. These multidisciplinary teams approached the work effort with a diversity of skills and a commitment to meet ambitious deadlines with community-sensitive, resource-conscious plans that would be implemented in a systematic coordinated effort of system expansion.

Two teams were assembled to undertake this planning process. The Blue Team focused on the planning of routes to feed the four new stations on the Blue Line's northeast extension. The Red Team focused on planning the changes necessary to feed the one relocated and nine new stations along the Red Line's northern extension. These teams were comprised of representatives from Service Planning, Service Scheduling, Community Affairs and Marketing.

The teams drew on other technical resources as needed during plan development. Representatives of the staff managing the construction of the new stations were consulted as planning progressed. Efforts to involve representatives of the communities and riders who would benefit and be impacted by the changes were pursued.

The resulting plans responded to community and rider concerns, met planning objectives, conformed to resource constraints and were completed on schedule and nurtured to implementation by the team effort. This paper summarizes the development of these multidisciplinary teams, reviews their work processes and outlines the challenges faced in successfully undertaking major bus system redesign efforts on a fast track schedule.

Making Bus Better in Chicago: Strategic Implementation of Customer-Derived Satisfaction Measures from 1995 – 2001: What Worked – What Didn't

Peter J. Foote, *Chicago Transit Authority*

Abstract. The first system-level, CATI-assisted, random-digit-dial telephone survey of Chicago Transit Authority (CTA) customer satisfaction and loyalty (1995), revealed the need for customer-focused improvements in CTA service, particularly for CTA Bus Customers. Subsequent biennial surveys (1997, 1999 and 2001) document the positive impacts of customer-focused initiatives on the customer satisfaction and loyalty of CTA bus customers, effectively doubling the share of bus customers between 1995 and 2001.

While improvements that were both statistically and practically significant were found in CTA heavy rail customer overall satisfaction and loyalty after only two years, growth in the same measures for CTA bus customers, admittedly more difficult to achieve, was slower, with similar gains among bus customers not achieved until 2001. However, while lagging behind, CTA bus growth in overall satisfaction and loyalty matched CTA rail's progress by 1999. The impact of bus growth on system level satisfaction was such that by 2001, CTA had essentially doubled the customer satisfaction and loyalty of its customers, while substantially improving its image as a market-oriented agency. The development and use of customer-derived service measures and management application of research findings were critical to the success of this project. Also critical were prioritizing efforts to improve bus customer service, and communication of survey results and recommendations throughout the organization.

This paper will document the methods used to measure and improve CTA customer satisfaction and loyalty from 1995 – 2001, identify critical drivers of CTA customer satisfaction, and discuss the grouping of customer defined service measures (49 CTA Bus service attributes) into summary "performance dimensions". The methods used to communicate the importance of customer-focused initiatives within CTA and how they have evolved over time, will also be discussed. The use of geographic market segmentation techniques to focus efforts, changes in CTA's markets over the time period, and the subsequent reversal of decades of bus ridership decline, will also be discussed.

Congestion Mitigation Systems Plan 2020 (CMS 2020)

Michael L. Morehouse, P.E., *Wilbur Smith Associates*; Melissa M. Leigh, *South Western Regional Planning Agency*; Kari E. Watkins, E.I.T., *Wilbur Smith Associates*

Abstract. The South Western Regional Planning Agency (SWRPA) and Wilbur Smith Associates (WSA) are currently undertaking a study that will evaluate opportunities to reduce traffic congestion in Connecticut's southwest corridor which includes Interstate 95 and the Merritt Parkway, and improve mobility and access within the corridor and with adjacent regions in the New York Metropolitan Area. The planning process will yield an innovative vision for the movement of people and goods within the study area and between adjacent regions. The basis for this vision will be customer-driven: what transportation services and facilities do commuters and shippers want and need?

Strategies for improving congestion in the corridor are initially being evaluated within three broad categories. First, a low capital investment approach will attempt to use transportation system and demand management (TSM/TDM) strategies in combination with lower capital infrastructure investments to achieve transportation system efficiency, incremental increases in capacity and safety improvement. Secondly, a vision optimizing rail assets will evaluate the use of the existing rail network through capital investment in the upgrade and expansion of infrastructure and service. Enhanced support of the rail system by ensuring appropriate inter-modal linkages for movement of goods and passengers will be a goal. Lastly, a vision optimizing highway/roadway assets will attempt to make best use of the existing highway/roadway network through capital investment in the upgrade and expansion of infrastructure and roadway-based transit services. This will include expanded implementation and use of transportation system and demand management techniques to better support the traveling public.

An innovative evaluation framework has been developed to evaluate the impact of certain transportation improvements on peak period travel demand. This framework integrates the travel demand model used by the Connecticut Department of Transportation with the FHWA's STEAM model and uses global positioning satellite (GPS) technology to update the travel-time skim tables in each model to better reflect "real world" congestion conditions in the study corridor during peak commuter periods. This use of GPS technology was applied to all major interstates, expressways, arterials and rail lines in the study area.

Each vision was tested using this innovative model to identify the best performing strategies in each of the visions. Emphasis was given to those strategies that had the greatest potential to affect corridor-wide travel behavior. Shifts in mode choice were extracted from the model to quantify user and system benefits. High performing strategies were then evaluated as part of a multi-modal, hybrid vision to quantify the actual benefits of comprehensive and coordinated improvements in the corridor. The final synthesis of strategies will define a corridor vision that will: (1) have the support of the traveling public and public officials; (2) blend appropriate elements of each of the strategies evaluated; and (3) provide short and long-range opportunities for congestion mitigation.

Lessons learned to date, as well as practical approaches to what worked and what didn't work in terms of developing strategies and devising evaluation methods will be shared.

TDM Effective Evaluation Model (TEEM): an Analytical Tool for Testing TDM and Land Use Strategies in a Corridor Context

William R. Loudon and Dustin K. Luther: *DKS Associates*; Jean E. Mabry and Sarah Kavage, *Washington State Department of Transportation*

Abstract: Over the past thirty years, concerns about fuel conservation, air quality, congestion mitigation, multi-modal accessibility and creation of livable communities have motivated planners to test the effectiveness of transportation demand management (TDM) and land-use/transportation strategies in reducing vehicle trips and VMT. Numerous analytical tools have been developed over time to address these needs, but none have been designed to be applied to test strategies as part of a major investment study in a congested regional corridor. The Washington State Department of Transportation (WSDOT) has sponsored the development of a model to forecast the potential effectiveness of TDM and land use strategies in the Trans-Lake Washington (SR 520) corridor that crosses Lake Washington from Seattle to the suburban east side of the Puget Sound Region. DKS Associates has developed the TDM Effectiveness Evaluation Model (TEEM) to meet WSDOT's needs. TEEM is designed to evaluate the potential effectiveness of fifteen different TDM strategies by predicting a change in AM Peak vehicle trips, daily vehicle trips, VMT, and person throughput in the SR 520 corridor. Each of the fifteen strategies can be tested either individually or in combination. To ensure transparency and accessibility of the model to the user, TEEM has been implemented in an Excel and given an easy-to-use interface. Ten case-study areas in the Trans Lake Washington Corridor have been tested with TEEM and the results have been used in the process of negotiating an inter-agency agreement for a corridor TDM/land use plan.

Transportation Utility Fee: The Oregon Experience

Carl D. Springer, *DKS Associates*

Abstract. Ten agencies in Oregon have adopted transportation utility fee (TUF) programs to augment shrinking roadway maintenance gas tax revenues. Three additional agencies are poised to adopt TUF programs this year, and stand to collect roughly \$10,000 per road mile annually through this new mechanism. Clackamas County (pop. 380,000) is in the process of developing a TUF program, and, if adopted, will become the largest agency in the state with this type of finance system. Preliminary TUF revenue forecasts for the county are \$15 to \$20 million annually. This is about one-quarter of the county's existing facility maintenance costs for transportation systems, and would be a significant supplement to current transportation finance programs. If adopted, this funding shift will provide county administrators with opportunities to re-task a portion of the gas tax funds to capital project investments, which are significantly under funded. The TUF development process in Clackamas County included a convergence of traditional travel demand forecasting with near-term traffic impact techniques to create a road user nexus at a parcel level. Many of the existing city programs use trip generation data published by the Institute of Transportation Engineers (ITE) as the basis for fee allocation, but a more comprehensive approach was desired for this process to better account for the diversity of land uses, and differences in rural versus urban road maintenance needs. To accomplish this, trip estimates were made using ITE methods and regional travel demand model methods as a cross-check. A major challenge was to make a reasonable assessment of travel activity for every building within the county. Each of the 97,000 residential tax lots and 7,000 non-residential tax lots were evaluated using tax assessor and state employment records to estimate travel activity and proportionately allocate fees.

The major steps of the TUF program development process involved:

- Screening existing activities for funding eligibility
- Estimating for average weekday trip activity for each building development
- Establishing fee tiers to simplify implementation and administration

Many lessons were learned during the process may have application to other communities that would consider this type of program. The foremost lessons include: a heightened need for integrated land use and employment data collection and monitoring techniques across agency departments, discrete differences between parcel level and regional level travel analysis related to truck trip generation and trip length research.

(The final report for the Clackamas County TUF should be available prior to the publication date for the conference – additional findings will be included, as appropriate)

Road maintenance in Oregon is tied to gas tax revenues as a primary funding source. State gas tax rates have not changed since 1993, despite three unsuccessful attempts by the legislature. The state gas tax rate is not indexed for annual inflation, so the state, county and city jurisdictions have effectively lost \$0.23 per dollar in maintenance buying power over the past ten years. Also, fuel-efficient vehicles have shaved off 8 percent of

the average gas consumption since 1990. These two factors are offset, in part, by increased vehicle-miles-traveled, which is up 21 percent statewide¹ during the same period. With minimal increases in lane-miles of roadway, the higher VMT also means a higher level of heavy truck impacts on regional facilities. The net effect for many jurisdictions, especially in urban areas, is decreasing maintenance dollars and increasing maintenance needs.

Street Utility Fee Augments Funding Shortfall

One solution to this funding dilemma that has been adopted by 10 cities in Oregon, to date, is a transportation utility fee. This type of fee allocates a portion of the recurring maintenance costs to all development located within the jurisdiction limits on a monthly basis. In general, costs are assigned proportionately to road usage, based on trip intensity or estimated vehicle-miles traveled. A few smaller cities (under 5,000 pop.) have assigned a flat fee rate for all road users without distinction between land use types or size. Clackamas County is currently in the public process to consider a transportation maintenance fee.

Case Study: Clackamas County

Clackamas County is located in the Portland-Vancouver metropolitan region with a population of 345,000 (2000 census) spanning an area about the size of the State of Delaware. The county maintains approximately 1,425 road miles with an annual budget of \$33 million (2002). According to county staff, this budget is approximately \$9 million below the level needed to cost effectively maintain these facilities. Local streets in unincorporated areas are typical targets for deferred maintenance in favor of investments in higher functional classes. Several local facilities have degraded to such a poor level as to be impassable by motor vehicle traffic.

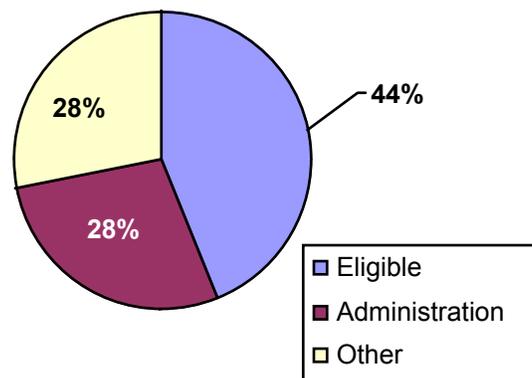
Study Objectives

The county worked with five local cities to develop a transportation maintenance fee (TMF) for their jurisdiction that involved the following three-step process:

- Screening existing maintenance activities for funding eligibility.
- Estimating average weekday trip activity for each development within the county limits.
- Establishing fee tiers to simplify implementation and administration.

The City of Portland, Oregon attempted implementing a similar fee program in 2001. One of the criticisms of their proposals was that the associated activities were too broad and not directly related to roadway maintenance. One

Fee Eligibility Screening



¹ Oregon VMT By Year, http://www.odot.state.or.us/tdb/traffic_monitoring/vmt.htm

example cited was tow charges for abandoned vehicles.

Fee Eligibility

In response, Clackamas County decided to consider only activities with a clear and direct benefit to roadway users. This included pavement maintenance and reconstruction, traffic signal, striping and sign repairs, and bridge maintenance, which in total accounts for about 44 percent of the annual budgeted amount (*refer to Fee Eligibility Screening Chart*) or \$16 million within the unincorporated portion of the county. Each participating city jurisdiction reviewed past maintenance spending trends to identify amounts to be recovered by the fee. The initial annual total considered as the basis for fee rate calculation was \$21.5 million.

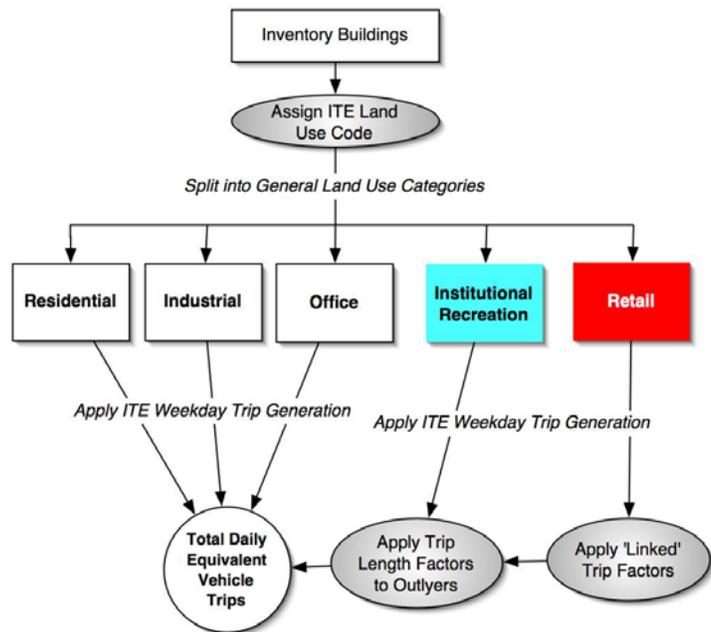
Parcel Level Trip Generation Analysis

The utility fee administration required that trip generation analysis be made for each of the tax parcels within Clackamas County. There were 97,000 residential tax lots and 7,000 tax lots with commercial, industrial, or other non-residential uses. A comprehensive review of these records was made by county staff to evaluate trip activity. The inventory and analysis process is summarized below.

1. Inventory Existing Buildings for Residential and Non-residential land use types – This work was done from tax assessor records, field inventories, and state employment data sources by county staff and interns.
2. Assign ITE trip generation codes types to each building based on local knowledge and field checking, where appropriate.
3. Compute Raw Trip Generation – Estimate daily trip generation based on ITE data.
4. Pass-By Adjustment – Factor retail uses for ‘pass-by’ discount to account for linked trips. ITE categories with detailed ‘pass-by’ data published in the Sixth

Edition of the *Trip Generation* research were applied as appropriate. For those categories without specific studies, a general factor of 30% was applied to retail uses in the ITE code 800 and 900 series.

5. Trip Length Adjustment – Apply trip length factors to outlying land use types relative to residential uses. A relative adjustment factor of 0.5 was applied to retail, school, day care, and library uses, and a 1.5 factor was applied to major recreational facilities. All other uses had a trip length factor of 1.0.



The calculation process primarily relied on published ITE *Trip Generation* data and recommended methods to estimate daily vehicle trip levels for each building or complex of uses. Initially, three levels of road usage were identified for possible inclusion in the road usage allocation process;

- Vehicle trip intensity (weekday daily trip ends)
- Vehicle trip length
- Truck trips

Trip intensity was computed for 86 land use categories reported by ITE. Trip length information was not applied explicitly to convert this to vehicle-mile-traveled. Instead, the trip length factors were expressed relative to residential trip lengths based on previous work² done for the county. The land use categories selected for these relative trip length factors were schools, retail, day care, library (generally much shorter than typical residential trips), and major recreational facilities (generally much longer than typical residential trips). All other land uses were not factored relative to residential uses. The relationship between heavy truck trips and the rate of pavement damage is well established. However, a literature review of published truck trip generation showed very limited data at the level of detail suitable for parcel level estimates. Therefore, a separate truck factor was not included in the calculation.

Table 1: Adjusted Trip Generation by Jurisdiction in Clackamas County

Jurisdiction	Residential Trips	Non Residential Trips	Total Daily Trips
Barlow	382	1,314	1,696
Canby	31,635	65,425	97,060
Clackamas Urban	211,479	497,666	709,145
Clackamas Rural	287,480	93,331	380,811
Estacada	6,015	21,455	27,470
Gladstone	28,665	35,336	64,001
Happy Valley	18,172	6,454	24,626
Lake Oswego	106,191	144,218	250,409
Milwaukie	58,724	126,264	184,988
Molalla	13,747	27,170	40,917
Oregon City	69,281	153,129	222,410
Portland	2,458	104	2,562
River Grove	1,081	840	1,921
Sandy	14,475	37,713	52,188
Tualatin	6,947	24,991	31,938
West Linn	70,470	49,103	119,573
Wilsonville	31,588	111,361	142,949
All Cities	459,831	804,877	1,264,708
All Unincorporated	498,959	590,997	1,089,956
Jurisdiction Total	958,790	1,395,874	2,354,664

Trip Generation Findings

The final trip generation findings show a grand total of 2.35 million vehicle trips using the above method. This was compared to the regional travel model daily trip estimates as a back-check. The Clackamas County total daily trips according to the 2000 Metro model were 2.38 million vehicle trips, a difference of less than 2 percent. Residential trips accounted for 1.0 million and non-residential trips were 1.4 million. This comparison validates the selected trip calculation methodology as a reasonable approach for use in implementing the TMF. Table 1 lists the adjusted weekday

² Don Ganer & Associates, “Clackamas County: Countywide Transportation System Development Charges Methodology Update Report”, September 18, 2001.

vehicle trips for each jurisdiction in Clackamas County.

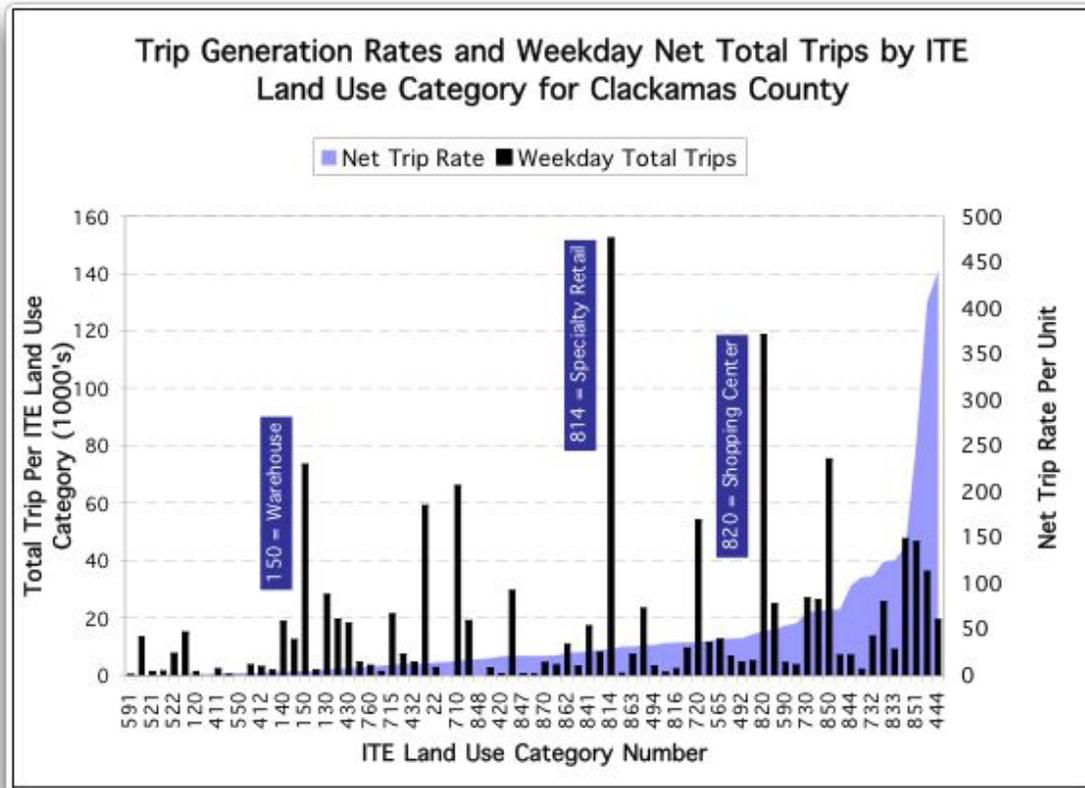


Figure 1: Non-Residential Trips Sorted by Trip Rate and Weekday Total Trips

Fee Allocation Approach

Residential land use categories were divided into two bins (single-family and other) and non-residential were divided into multiple bins based on a sorting process. The bins would be used to allocate costs similar to the approach taken in the Cities of Lake Oswego, Eugene, Springfield and Tigard.

The trip generation estimates for Clackamas County derived from the ITE methodology was sorted by land use category based on the net weekday trip rate (trips per land unit) – See Figure 1 above. Trip rates increase from left to right as shown by the blue line in Figure 1, with values ranging from 1 to 450. In a few cases, the trip rates were normalized to an equivalent land coverage basis by applying density assumptions where the land use unit was not KSF (1,000 gross square feet of building area). For example, a trip rate based on number of employees was converted to an equivalent basis by factoring for the assumed number of employees per KSF. By making these types of adjustments, the net trip rate is more comparable across all ITE categories. The ITE code categories are listed on the x-axis of the chart, and the estimated weekday trips by ITE category are shown in bars. The single tallest bar is for Specialty Retail (ITE Code 814) with 151,000 daily trips, followed by Shopping Center (ITE Code 820) with 118,000 daily trips and Warehouse (ITE Code 150) with 73,000 daily trips.

This trip rate and trip quantity information was used to develop the non-residential rate tiers. The concept is that each of the land uses within a given tier would be charged based on a common trip rate, rather than specific rates as defined by ITE. Grouping trip rates helps to correct for cases where ITE data for a given land use is limited, and it significantly simplifies fee administration. Boundaries between the five non-residential tiers were selected to minimize the ratio between bin rates and ITE rates for a given land use category.

The group trip rates were reconciled against the trip calculation using individual ITE category rates to ensure that the countywide totals were consistent. The results of the comparison are shown in Table 2. The row titled ‘land use units total’ refers to the variable applied to calculate trips. For non-residential uses, it most typically is 1,000 gross square feet floor area. The great majority of non-retail uses fall into Bin #1 or #2 (82 percent) whereas only two percent lies in the highest trip rate, Bin #5.

Table 1: Trip Rate Reconciliation Summary -- Detailed Trip Rates vs. Bin Trip Rates

Bin #	Non-Residential Bins					Residential		Totals
	1	2	3	4	5	10	11	All
Trip Per Land Use Unit	2	10	25	40	100	9.57	6	
Land Use Units Total	92,514	17,689	14,029	6,136	3,205	98,259	30,126	261,958
Trips By Bin Rate	185,028	176,895	350,729	245,446	320,484	940,339	180,753	2,399,674
Trips By Detailed ITE Rate	166,383	168,877	315,343	251,259	280,656	940,339	188,976	2,311,834
Difference (Bin - Detail)	-18,645	-8,018	-35,386	5,813	-39,828	0	8,223	-87,841

Average Rate Based on Detailed ITE Rate Calculations	1.80	9.55	22.48	40.95	87.57	9.57	6.27
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Initial Fee Schedule

The initial cost per vehicle trip was calculated based on \$21.5 million eligible annual costs yielded about \$1.50 per daily vehicle trip that originates or ends within the county. A preliminary cost for each land use category was developed based on the bin trip rates and unit cost per trip, which yielded the following sample fee schedule (per month):

<u>Sample Land Use Type</u>	<u>Monthly Fee</u>
Single Family Detached Dwelling Unit:.....	\$15
Neighborhood Shopping Center (50,000 square feet lease area):.....	\$3,000
Apartment Complex (200 units):	\$1,800
Elementary School (500 students)	\$1,000

This initial estimate was roughly three times the fee rates found in comparable Oregon communities. Therefore, further technical review was made regarding the appropriate

mix of maintenance activities to reduce the fee closer to current ‘market’ costs. State law requires that a fee system have a clear nexus between actual maintenance costs and the fee collected. However, an initial finding of this study showed that, although the county could collect up to \$15 per single family dwelling unit, it may be better received by the community if only a portion of those costs were recovered through this fee system. Part of this discussion involved how the fees would be collected with multiple jurisdictions involved since the cost basis (roadway maintenance cost per road mile) varied significantly between each jurisdiction. To date, the discussion has led to funding the least common denominator between all jurisdictions, which had the lowest fee rate. Instead of \$15 monthly per single-family dwelling unit, the latest rate³ would charge \$2.17 for the same unit. The final data and process description for the Clackamas TMF is illustrated in Figure 2 on the following page.

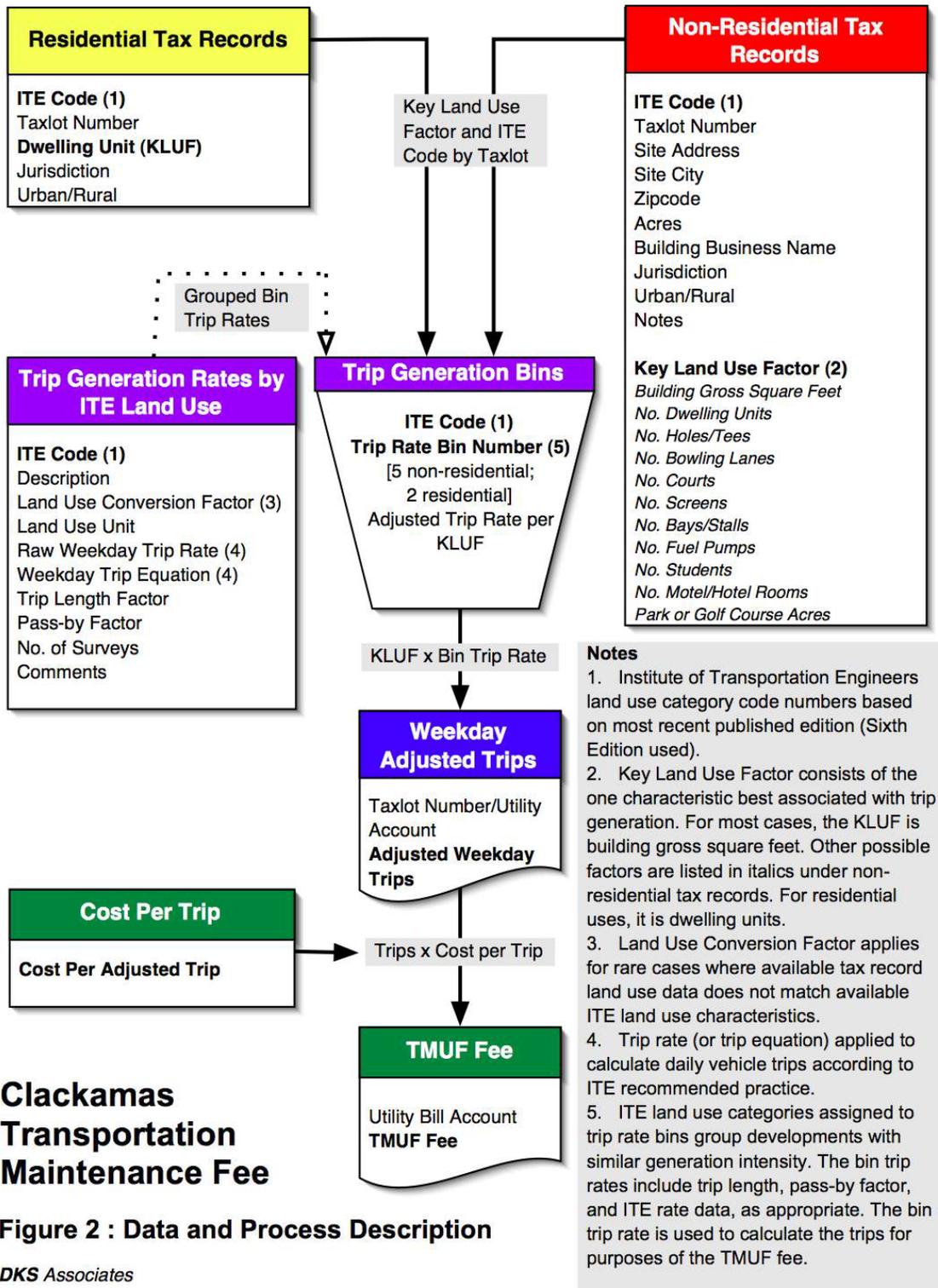
Oregon Jurisdictions To Date

The following list in Table 3 summarizes a few basic facts about the Oregon communities that have adopted or are pending adoption on transportation utility fees. Of the jurisdictions shown, Lake Oswego, Tigard, and Clackamas County are considering TUF⁴ (or TMF) ordinances, while the remaining have adopted TUFs. The list also highlights the population, gross annual revenue collected by the TUF and basic averages that are convenient for comparisons between jurisdictions. The population for Clackamas County reflects the fee area to be served by the TMF (236,000), which is about two-thirds of complete countywide population. The household monthly fees ranges from just under \$2 up to \$5. In terms of revenue per person, the range is \$12 to \$48 per year.

Table 2: Transportation Utility Fees in Oregon (Sorted by Fee Per Single Family Unit)

City	Population	Gross Annual Revenue	Monthly Fee for Single Family Detached Unit	Annual Revenue Per Capita
Ashland	19,490	\$734,000	\$5.12	\$37.66
Medford	59,990	\$2,900,000	\$4.64	\$48.34
Lake Oswego	35,400	\$1,200,000	\$4.59	\$33.90
Wilsonville	12,985	\$482,713	\$4.48	\$37.17
La Grande	12,885	\$200,000	\$4.00	\$15.52
Eagle Point	4,665	\$80,000	\$3.00	\$17.15
Tualatin	21,345	\$620,000	\$2.92	\$29.05
Eugene	140,000	\$5,700,000	\$2.90	\$40.71
Tigard	43,500	\$1,605,000	\$2.70	\$36.90
Clackamas County	236,000	\$4,200,000	\$2.17	\$17.80
Talent	5,065	\$62,400	\$1.96	\$12.32
Springfield	52,000	\$1,000,000	\$1.75	\$19.23
Phoenix	3,970	\$60,000	\$1.55	\$15.11

³ “Clackamas County Transportation Fee Analysis and Utility Formation Study”, Financial Consulting Solutions Group, April 2003.



Clackamas Transportation Maintenance Fee

Figure 2 : Data and Process Description

DKS Associates

⁴ The City of Gresham is also considering a TUF, but their preliminary rates were not available for publication.

Implementation Issues

The technical analysis of road usage by parcel level was a significant challenge for the Clackamas County community. However, the administrative and policy-making issues associated with implementing a comprehensive new fee system for two-thirds of the population was a greater effort in many regards. The following sections highlight the most notable technical and administrative implementation issues encountered during the Clackamas County study.

Resolving Basis for Cost Assumptions

While the larger jurisdictions had comprehensive cost management tools for evaluating transportation maintenance activities, many of the smaller cities lacked detailed historical records that identified both the actual expenses and the system needs. With deferred maintenance of the roadway system being a common solution for many jurisdictions, the actual funding required to maintain minimum system performance measures (e.g., pavement integrity) often was unknown. The preferred starting point for the cost basis discussion was a comprehensive pavement management system and regular pavement inspection.

Specificity of Parcel Level Trip Generation Versus Available Activity Data

Residential trip generation estimation was a straightforward exercise based on readily available data. However, many of the public records for non-residential uses lacked sufficient details to match up with variables reported in the *ITE Trip Generation Manual*. A team of student interns was assigned the tasks of uncovering essential details about roughly 7,000 industrial, commercial, school and other non-residential generators. This work spanned several months and included field visits, phone calls to businesses and property managers, and reviews by aerial photographs. The resulting data set describing building floor area, employees, and business type was incorporated into an expanded information management system to be maintained by the county.

Nexus Versus Market Forces

A clear technical case was made that would have supported a significantly higher TMF fee that was consistent with established maintenance needs and state legislation. This initial fee of \$15 per single-family dwelling unit (as a comparative indicator) was subsequently reduced by policy choices to position the rate schedule within the general limits adopted by other communities. The current rate program would charge about \$2 per single-family unit.

Billing Administration and Multiple Jurisdictions

One of the initial concepts for TMF administration would have used a central billing agency (the county) to build on a billing system used for tax assessment. However, participating cities were not satisfied with the sole responsibility of fee collection and distribution to reside with the county, primarily because of possible misperceptions by city elected officials about fairness and equity on the county's behalf. A range of administration schemes was considered that included the least, average and highest cost denominators and uniform and area-specific fee programs (i.e., each city would establish

and maintain their own fee program). Under the highest common denominator scheme, several of the participating cities would ‘over collect’ relative to their local needs, and the balance would be distributed to the members with higher unit maintenance costs.

A major policy choice was to avoid the need for re-distributing fees collected in one jurisdiction for application in another. These types of policies choices were very significant in shaping the level and form of the current fee rate program being considered by Clackamas County, which, as presently defined, would use existing utility program billing systems (water, sewer) for the transportation utility fee administration rather than a countywide tax billing system.

A final billing issue was: exactly who is charged? Residential customers are generally identified by tax records, and these accounts can be readily monitored. Tax records typically have non-residential landowners, but not necessarily the business operators or landlords. An on-going policy decision involves choosing between tax lot owners and business operators as the basis for fee collection. A general preference was stated by the elected officials reviewing the program to target business operators that are responsible for management at given business location, and accountable for these types of recurring costs of operation. However, the information system for monitoring changes in business operators around the county (business licenses and permits, etc.) is not well coordinated with other more comprehensive systems maintained by the tax assessors office. There is a clear need for re-organization of these data management systems to make the fee collection and administration costs effective.

Public Outreach

A separate advisory committee from the community was formed after the draft program policies and rates were identified to present and refine the TMF program. This advisory body re-evaluates the policy and cost implications to their respective constituents of the business, educational, and development community, and provides feedback to county staff leading the program development. Their recommendations will be forwarded to the county commissioners for their review of the TMF program ordinances for possible adoption.

Conclusions

The TUF (or TMF) program is a significant potential contribution to a jurisdiction’s revenue system to recover maintenances costs that are increasingly not covered by other sources such as state gas taxes. Revenue collected by adopted TUFs range from \$12 to \$48 annually per capita. The technical aspect of the nexus analysis requires extensive and well-coordinated data sets that may extend beyond the limits of existing information systems. A larger aspect discovered in the consideration of a TMF in Clackamas County was the associated policy choices and public education required to implement the program.

Acknowledgements

The author acknowledges the assistance of several colleagues during the technical analysis, review of the Clackamas TMF study and preparation of the this paper. These included Mr. John Ghilarducci, Financial Consulting Solutions Group, Redmond, Washington; Mr. Ron Skidmore, Senior Transportation Planner and Ms. Pam Hayden, Senior Policy Analyst, Clackamas County Department of Transportation and Development, Clackamas, Oregon; and members of the study Technical Advisory Committee.

Coordinated Federal and State Environmental Processes for Doyle Drive – A Case Study

Dina Potter and Susan Killen, *Parsons Brinckerhoff*

Abstract. The objective of this paper is to illustrate how strong coordination leads to the successful combination of the federal and state environmental processes by providing a case study of Doyle Drive – a unique transportation project within a National Park and National Historic Landmark District.

This case study recognizes institutional and regulatory constraints and opportunities as well as an understanding of the importance of collaboration and coordination with agencies and the public.

Scope and Reason for Paper: Doyle Drive is the southern approach of the Golden Gate Bridge and regional transportation connection between San Francisco and points north. It is located in the Presidio of San Francisco, the oldest continuously operated military post in the nation. The Presidio spans 1,280 acres; boasts spectacular views, a diverse ecosystem, a dynamic shoreline and historic forests; as well as bordering the largest chain of marine sanctuaries in the northern hemisphere. All of these characteristics make environmental stewardship critical to the success of replacing this aging facility.

The case study will demonstrate the multiagency, multidisciplinary, and multilevel coordination process created to develop broad consensus among three federal land managers and FHWA and over 12 key state and regional agencies throughout the environmental evaluation process – from the project purpose to the development of potential solutions to managing other inevitable challenges such as staff changeover, lack of staff, and differing individual styles within key agencies.

Conclusion: The multiagency, multidisciplinary, and multilevel coordination process provided continual interaction among the various agencies and the community – at multiple levels – to identify differing goals, lack of staff continuity maintain open communications, and moving the project toward an acceptable conclusion while managing.

For more than 60 years, Doyle Drive has wound through the gentle hills and green forests of the Presidio, providing sweeping views of San Francisco Bay to residents, commuters, and tourists. The roadway links San Francisco, the Peninsula, Marin and points north by way of the majestic Golden Gate Bridge, one of the most recognized landmarks in the world. Implementing a vision for Doyle Drive presents a rare opportunity to achieve needed safety improvements while improving the alignment and aesthetic details of the San Francisco link to the Golden Gate Bridge. Doyle Drive could more sensitively interface with the Presidio, which has now become part of the national park system—rivaling Golden Gate Park as San Francisco's premier open space.

The objective of this paper is to illustrate how coordination affects the success of the federal and state environmental processes by providing a case study of Doyle Drive – a unique transportation project within a National Park and National Historic Landmark District. This case study discusses the multiagency, multidiscipline, and multilevel coordination process among three federal land managers and Federal Highway Administration (FHWA) and over ten key state and regional agencies throughout the environmental evaluation process for the Doyle Drive approach to the Golden Gate Bridge. This case study recognizes institutional and regulatory constraints and opportunities as well as an understanding of the importance of collaboration and coordination with agencies and the public.

Setting

Doyle Drive, the southern approach of US Highway 101 to the Golden Gate Bridge, is 2.4 kilometers (1.5 miles) with six traffic lanes. It links Marin County and points north to the city of San Francisco and the Peninsula via the Golden Gate Bridge. It is located in the Presidio of San Francisco - and has served as a military reservation since its establishment in 1776 as Spain's northern - most outpost in the New World through the Cold War - making it one of the longest-garrisoned posts in the country, and the oldest installation in the American West.

The Presidio has been a National Historic Landmark District (NHLA) since 1962 and part of the Golden Gate National Recreation Area (GGNRA) since 1972. Its 1,280 acres boast spectacular views, a diverse ecosystem, a dynamic shoreline and historic forests; as well as bordering the largest chain of marine sanctuaries in the northern hemisphere. All of these characteristics make environmental stewardship critical to the success of replacing this aging facility.

In 1994, management of the Presidio was transferred from the US Army to the National Park Service (NPS) and in July 1998, the management was divided among to two federal agencies: the Presidio Trust (the Trust) and the NPS. Congress established the Trust to manage the buildings and infrastructure left by the military and to make the resource self-sufficient by the year 2013.

Project Purpose

Currently, Doyle Drive has non-standard design elements, including 2.9 to 3.0-meter (9.5 to 10-foot) wide travel lanes, no fixed median barrier or shoulders, and exit ramps that have tight turning radii. Since 1968, plastic pylons have been used to separate oncoming traffic and reverse the direction of the two center lanes to serve the peak flow direction. Except for off-ramps at the Golden Gate Bridge toll plaza, no vehicular access into the Presidio is available from Doyle Drive.

The 65-year-old Doyle Drive is approaching the end of its useful life, although regular maintenance, seismic retrofit, and rehabilitation activities are keeping the structure safe in the short term. Further structural degradation caused by age, the effects of heavy traffic and exposure to salt air will cause the structure to become seismically and structurally unsafe in the coming years. In addition, the eastern portion of the aging facility is located in a liquefaction zone, which presents the potential for structural failure during an earthquake.

As the primary north-south freeway link in coastal California, Doyle Drive carries almost 100,000 vehicles daily, including public transit. If this vital regional connection were to be inoperable, or even severely restricted, traffic throughout the Bay Area would be seriously disrupted. However, replacing a heavily used urban roadway in an environmentally sensitive national park that must become self-sufficient presents significant technical challenges. Design challenges include the need for a wider roadway with increased access to meet safety requirements while using as little additional land as possible. The roadway must minimize impacts to natural, cultural, and natural resources. In addition one of the greatest challenges is to construct a roadway while maintaining the existing traffic capacity.

Long History:

The history of Doyle Drive dates back to 1933 when its construction began with the Golden Gate Bridge. The Golden Gate Bridge District has requested that the State widen and reconstruct Doyle Drive to handle increasing congestion since 1955; however, all widening proposals have been dropped due to public concerns regarding impacts. In 1970, after ten people were killed in an accident, the National Transportation Safety Board recommended that Doyle Drive be brought up to current freeway design standards. In 1973, a Draft Environmental Impact Statement (DEIS) was completed for reconstruction of Doyle Drive as an eight-lane highway with a fixed-median barrier. Again, the public objected to the proposal and the following year, the State legislature passed the Marks Bill, which prohibits the California Department of Transportation (Caltrans) from widening Doyle Drive to more than six lanes without the specific approval of the San Francisco Board of Supervisors.

Caltrans developed two alternatives in 1988 after the San Francisco Board of Supervisors requested that the State develop alternatives that would not increase the number of vehicles using Doyle Drive on an average daily basis. Issues regarding ramp closures at the State Route 1 interchange with Doyle Drive that would have affected traffic and circulation in the Presidio and in the neighboring Marina and Richmond neighborhoods were never resolved and a preferred alternative was not identified.

In 1991, the San Francisco Board of Supervisors established the Doyle Drive Task Force, consisting of representatives from various local governments and public and private organizations. The Task Force was charged to consider design alternatives and develop a consensus on a preferred alternative. The 1993 *Report of the Doyle Drive Task Force to the San Francisco Board of Supervisors* proposed the concept of a scenic parkway through the Presidio. This parkway concept envisioned a six-lane roadway with an eastbound auxiliary lane between the State Route 1 off-ramp and a new direct access point to the Presidio. In principle, the Board of Supervisors unanimously approved the recommendations of the Task Force and urged Caltrans to expedite inclusion of rebuilding Doyle Drive in the next State transportation funding cycle.

In 1993, Caltrans completed a project study report for the replacement of Doyle Drive, putting the project on the State's Transportation Improvement Program (TIP). The Task Force's recommended concept was one of the alternatives evaluated in the project study report, but as is standard in a project study report, a preferred alternative was not identified. Identification of a

Preferred Alternative is pending completion of the National Environmental Policy Act (NEPA) and California Environmental Quality Act (CEQA) environmental review processes.

In 1994, the San Francisco County Transportation Authority (SFCTA) initiated the Doyle Drive Intermodal Study, which was funded by a Caltrans State Planning and Research Grant. The Intermodal Study was “to further the development and ultimate implementation of a realistic and fundable replacement for Doyle Drive.” In 1996, the Authority released the *Doyle Drive Intermodal Study*, which supports the Doyle Drive Task Force and the 1994 General Management Plan Amendment (GMPA) recommendations to design the Doyle Drive replacement as a “parkway” and further defines the parkway design. It also emphasized making multi-modal and direct vehicular access into and out of the Presidio central features of the Doyle Drive replacement design.

In the 2002 Final Presidio Trust Management Plan (PTMP), the Trust stated that it “supports long-range safety improvements on Doyle Drive and is actively involved in the planning process. The Trust will review and evaluate proposals and determine the consistency and compatibility of those proposals with park resources and values” (PTMP, August 2002). Detailed planning and implementation of the PTMP concepts is ongoing.

SFCTA, Caltrans, and FHWA are currently drafting design and engineering alternatives for Doyle Drive to improve traffic safety and structural stability. This study, the Doyle Drive Environmental and Design Study, will result in the selection of a Preferred Alternative and environmental clearance enabling the project to proceed to final design and construction. It is this study that serves as the basis of the case study.

Challenges

It was recognized from the outset of the Environmental and Design Study that many different local, regional, state, federal and transit agencies will have varying degrees of input and influence on the project. The strategy was to work with the agencies to identify common goals that all can agree to, then to include them in the development of project elements to meet those goals. This, coupled with the high degree of public and local neighborhood interest in the replacement of Doyle Drive, presented many challenges to the project team to ensure that there would be sufficient collaboration and coordination to move the project forward. The following discusses some of the most relevant and important challenges to move the project forward.

Challenge: Project History

The project has a long history. In early phases the citizens played a pivotal role in the commitment to maintain and not increase capacity and to develop a parkway concept. Commitments were made regarding concepts and capacity that need to be honored.

From the outset, the project team recognized that project history was important. The project team must respect, know, understand and use the project history – building credibility and moving the process forward. The project team researched the past history of the project and other projects in the surrounding area as well as conducting stakeholder interviews during the first months of the

design and environmental phase. The team also considered the political realities from both a neighborhood and agency perspective. The role of the Trust solidified over time, as detailed development and implementation of the Trust's plans continued. The changing relationship of the Trust and the citizens in the surrounding neighborhood also can be adversarial and there was excitement and doubt about the potential success of the Doyle Drive plans.

In establishing committee membership for the project, as part of an extensive public outreach program, the team incorporated roles for past players, drawing from past citizens and agency staff for the Executive Committee, the Citizens' Advisory Committee and the technical committees.

Most importantly the past work and commitments were openly acknowledged and the results of the design and environmental studies has been openly communicated. During preliminary engineering the parkway concepts were taken forward as part of the alternatives development and screening. Other alternatives were also considered. The engineering narrowed down the possible solutions – demonstrating that an at-grade facility with a “parkway” like feel due to vegetation and so forth is not possible within the narrow envelope. This envelope is important to recognize, as the design has also needed to be sympathetic to the park, the nature of the park as a National Historic Landmark. All parties are continuing to be engaged in development of additional alternatives that honor the parkway as a concept, the maintenance of the “narrow” right-of-way to respect the National Historic Landmark District while providing a safe roadway and gateway to the Golden Gate Bridge.

Challenge: Regulatory Environment

The project is currently undergoing environmental review and preliminary engineering. The combined Environmental Impact Statements and Environmental Impact Report (EIS/EIR) is being prepared under the National Environmental Policy Act (NEPA) and the California Environmental Quality Act (CEQA). Some of the regulatory considerations include but are not limited to:

Federal

- National Environmental Policy Act (NEPA)
- Historic Preservation Act (Section 106)
- Department of Transportation Act of 1966 (Section 4(f))
- Endangered Species Act
- Clean Water Act (Section 404)
- Floodplain Management (Executive Order 11981)
- Presidio Trust Management Plan

California

- California Environmental Quality Act (CEQA)
- California Coastal Act

City and County of San Francisco

- Planning Code

- Zoning Code
- General Plan
- Park Code

With a wide range of regulations and requirements that the project must meet, the project team acknowledged that all the stakeholders would need to have roles that inspired cooperation, communication and collaboration. The project team, recognizing federal, state and local roles defined the responsibilities of the agencies in helping to meet the regulatory requirements at the outset and incorporated their responsibilities into project development – assigning roles for the agencies on the Executive Committee and technical committees.

The project team also experienced several regulatory and guidance changes resulting in a changing project climate. The team initially had a more limited schedule and was not as anticipatory as became necessary as the schedule lengthened. As the project progressed and feedback from the agencies and length of the study demonstrated additional mechanisms needed to be put into place to signal the changes well in advance. The project team increased its legislative network to avert additional regulatory “surprises” both at the federal and state level. The project team, however, continues to be challenged by ongoing planning and implementation of the property owner and additional channels of communication and partnering are in development and implementation. Even as the project has matured additional partnering “refreshers” are required to keep all key players at the table in a collaborative mode.

Challenge: Multiple Agencies/ Multiple Departments

The federal lead agency is the Federal Highway Administration (FHWA) and the local lead agency is the San Francisco Transportation Authority (SFCTA). This lead position is further complicated by the land manager – having similar authority - the Presidio Trust and the Golden Gate National Recreation Area /National Park Service. These two agencies have authority as lead agencies of projects on the Presidio property.

Lead and Cooperating Agencies

- San Francisco County Transportation Authority (SFCTA) (local lead agency)
- Federal Highway Administration (FHWA) (federal lead agency)
- California Department of Transportation (Caltrans)
- Golden Gate Bridge and Highway Transportation District (GGBHTD)
- Golden Gate National Recreation Area/National Park Service (GGNRA/NPS)
- Presidio Trust
- Veterans Affairs

At the outset of the project it was recognized that input from key agencies would be essential in reaching consensus on the issues and alternatives, including a Preferred Alternative. To meet this challenge at the project inception an Executive Committee was established. The Executive Committee included land owners/stewards including the Trust and the GGNRA/NPS. The Executive Committee was to receive projects updates and provide input into project direction and other policy matters. Executive Committee was to provide coordinated input on a regular basis and generally provide consensus or changes to study direction particularly with policy

matters. The project team learned that the decision-making process needed to be explicitly determined and conveyed at project start-up to have key staff at the table and also to allow the public process to inform the decision-making. .

The Executive Committee began with a shift in some the attendees from the key agency decision makers to their representatives. It was assumed that the decision makers were kept abreast of all the activities and discussions of the committee and that all minutes of activities and critical issues discussed. This was an implicitly assumed that should have been made explicit and incorporated in the charge of the Executive Committee. This information should have led to an early adjustment in the protocols for Executive Committee recommendations and a plan for decision-making.

Adding to the agency role challenges was the changeover of several of the key leaders who had participated in the initial meetings and, therefore, had established their agencies general position regarding the project. There were no early mechanisms to recognize that true decision makers were not present and action was required. As project progressed and the representatives postponed decisions – it was recognized that key decision makers often had not been briefed by their representatives. The decision makers' role was then revised to be more selective in terms of issues elevated to them and number and attendance of counterparts at meetings. Key issues are being identified to escalate to key decision makers. From the beginning there was an unfilled mandate to implement a process that recognized that the decision makers must support project decisions and direction. The project team learned that the limitations of agency staff involvement needed to be dealt with early and honestly.

The project team also found other actions increased meeting and participation success. Continuity of the meetings was important. Establishing regular meeting times, format set expectations that could easily be transferred and integrated into each agencies forum for putting issues on the table. The changeover in leadership was mitigated in part by the attendance on the landowner side by their representatives. On the roadway side the key federal and state staff faced changes in leadership and champions of the project.

Other multiple agency approaches to meeting challenges included field trips with agencies provided ownership and demonstrated the need and scale of the project as well as importance. The project became less abstract and energized participation. Where possible, the agencies had a single point source coordinator. This helped immensely in coordinating comments and ensuring one point of contact to establish meetings and dos forth. These positions were as good as the coordinators abilities to sort through agencies priorities.

Challenge: Technical Analysis

The technical analysts faced many challenges including multiple disciplines and differing agency approaches even within the same discipline. In addition, the landowners continue to face competing resources values and priorities – predominantly between the natural and historic resources.

Initially to streamline the process, in addition to the Executive Committee, it was determined that the technology experts from the project team and the agencies would need to work closely. To further maintain the momentum and increase the opportunity to minimize comments on the technical work the early technical meetings with the experts from the agencies representing specific expertise would allow for dialogue between all parties concerned in advance of the methodology reports being submitted for review. Technical committees were formed within the different disciplines.

For the technical analysis, all participants (the agencies) were given copies of the technical approach (the methodology) for review in advance of the technical studies. A meeting of the technical experts from the various agencies was then convened and the methodologies were adjusted as necessary. Once the reports were complete copies of the reports were distributed to the agencies for their review.

The project team consistently maintained a record of agency comments on various technical documents to provide a thorough record of agency position and participation. Conflicting comments and/or resolution was reached in the multiagency technical meetings. Among successful tools to communicate were matrices of comments made on technical reports and the EIS as part of the record of comments. The matrices included the comment, the agency making the comment and a proposed response. Once the commenter had a chance to view the manner in which the comment was being responded to - meeting was called between the technical experts on the project team to meet with the technical experts from the agencies.

Once the response to comments was resolved the technical reports were revised and issued. The information was then incorporated into the EIS/EIR. This worked well, initially, until additional players from the agencies not involved in the technical previous technical meetings reviewed the admin draft EIS/EIR. Additional comments and issues were brought up. The project team learned the necessity of getting a commitment from agencies for “rules” of continuity if there are staff changes or additions.

In addition, while early coordination was important, the team had too many meetings too early for which information was developed before alternatives were complete

Challenge: Project Timing/ Process Timing

The project schedule called for completion of the EIS/EIR and Record of Decision (ROD) in less than three years. Given the limited range of alternatives and the nature of the corridor this seemed to be a reasonable expectation. However, the project team needed to make course corrections based on a review of a greater than expected number of alternatives and sequential and lengthy review times for the various agencies. The resolution of disagreements in technical findings also increased the project schedule. The development of the schedule relies early by in from all the participants and reasonable but not excessive review times agree to by all parties.

Generally, a 30-day review period was desired for all technical reports. This was an agreement reached at the Executive Committee and agreed to by all agencies early in the project. In addition, FHWA had some prescribed review periods in their streamlining effort that in a

Memorandum of Agreement with Caltrans (usually 30-45 days). The reality was that often the federal and state agencies required much longer review times because of limited staff availability and conflicting priorities. The agencies were overly optimistic and did not factor their needs appropriately into the schedule. This continues to be a challenge.

In 1989, the Base Closure and Realignment Act of 1988 designated the Presidio for closure. In 1994, the U.S. Army departed and control of the Presidio was transferred to the National Park Service (NPS). In 1996, the U.S. Congress created the Presidio Trust (Trust). The Trust is a non-profit corporation of the U.S. government and is governed by a seven-member board of directors. It aims to achieve financial self-sufficiency for the Presidio by fiscal year 2013. In 1998, the Trust assumed management for the non-coastal areas (approximately 80 percent) of the park while the NPS continues to manage the 58.7 hectares (145 acres) of coastal areas.

To meet its mission, the Trust continues planning and implementation of its plans. This means that often plans, such as priorities for the use of buildings within the project corridor, changed over the duration of the study. While mutual planning was possible in some situations, and in fact, access to the Presidio is on of the Presidio's own desires being incorporated into the Doyle Drive planning, more often than not planning was not coordinated with consideration of the stages of the Doyle Drive study. In other cases, some buildings, which had been designated as not necessary, were re-designated as buildings of greater import. The commitment of all concerned to making the plans work and the "replacement" of Doyle Drive into the context the plans work is essential. The project team has increased its efforts to remain open and communicate potential changes so that both the Presidio and the Doyle Drive projects can remain flexible and responsive to changes but still maintain project momentum and direction. This will continue to be a project challenge in this dynamic environment. Communication regarding plans must be open, honest, and continuous.

The project team also has faced a recent and monumental challenge: choosing a Preferred Alternative as Economic Realities Change. The project study now is scheduled to take four plus years – a time during which the economic realities of the Bay Area, and in fact, the Country changed. The challenge to continue to evaluate the alternatives on all merits – environmental, operating, and economic becomes increasingly difficult. The alternative cost estimates continues to rise somewhat as the resources to develop the alternatives decreases. At the same time some of the alternatives that appeared to be "favorable" from an environmental perspective become less attractive in comparison to the cost of those which do not require incorporation of a tunnel facility into their design. The project team has had to recognize the need to seek out financial resources continually for the implementation of the project.

Conclusion

The multiagency, multidisciplinary, and multilevel collaboration process provides continual interaction among the various agencies and the community – at multiple levels – to identify challenges and approaches to move the project toward an acceptable and responsible conclusion. The challenges are many and can be met in many ways – always re-evaluating and turning ongoing lessons learned into action to move the process forward.

The project team must respect, know, understand and use the project's history. The team must approach the challenge of project history by:

- Researching media archives/project files
- Conducting stakeholder interviews
- Recognizing the political realities
- Incorporating "roles" for past players
- Incorporating /communicating past results

The project team must identify the regulatory requirements and:

- Understand roles and responsibilities
- Understand/anticipate changing rules and regulations
- Cooperate
- Communicate
- Collaborate

The project team must effectively work with multiple agencies/ multiple departments by:

- Defining roles and responsibilities
- Establishing effective and well-defined working groups including technical staff, agency coordinators, agency decision-makers and the public
- Determining the decision-making process at project start-up.
- Understanding the limitations of agency staff involvement and deal with early and honestly

To manage the technical analysis, the project team must:

- Recognize lead agency and land owner roles/technical working groups
- Get approval of methodologies in advance of analysis
- Review comments and resolve differences in advance of text changes
- Use agency leaders to resolve competing resource issues within agencies
- Develop procedures for issue resolution

To effectively manage the project schedule and timing of the process, the project team must:

- Develop a realistic schedule at project start-up
- Make the schedule development an interactive exercise, providing ownership of all parties
- Identify areas of potential risk
- Look for streamlining opportunities
- React to change, providing flexibility

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Before And After Studies for New Starts Projects

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Abstract. In April, 2001, FTA issued a new regulation that requires projects receiving New Starts funding to collect information on predictions and conditions prior to the construction of the New Start project, and conditions two years after the project is opened. At a minimum the following characteristics of the project are to be addressed: project scope, capital cost, operating and maintenance costs, operating plans, and travel demand. Project sponsors are to analyze this information to determine the impacts of the project and reasons for any differences between predicted and actual outcomes. The intent is to capture this information at the conclusion of Alternatives Analysis studies, preliminary engineering, prior to the signing of a Full Funding Grant Agreement and two years after project opening. For the first time, information on the impacts of New Starts projects will be collected in a systematic way. One of the benefits of such a program will be that planners will gain insights that will contribute to better planning for New Starts projects through a better understanding of the underlying causes of the differences between predictions and actual results.

This presentation will describe the technical, procedural and institutional issues involved in conducting a study drawing upon information developed over a number of years. The basis of the presentation will be guidance that FTA is currently developing for grantees undertaking these studies.

The Federal Transit Administration's (FTA) *Final Rule on Major Capital Investment Projects* (December 2000) includes a provision, commencing April 2001, whereby sponsors seeking a Full Funding Grant Agreement (FFGA) for their New Starts project must submit to FTA a plan for the collection and analysis of information leading to the identification of the impacts of the project and the accuracy of the forecasts which were prepared during project planning and development. As a condition of receiving an FFGA, project sponsors must commit to carrying out the defined elements of the aforementioned plan, resulting in the completion of a Before and After Study. The Study has two distinct and important purposes:

- (1) to expand insights into the costs and impacts of major transit investments; and
- (2) to improve the technical methods and procedures used in the planning and development of those investments.

To accomplish the first purpose - insights into costs and impacts - the Study identifies the actual costs of the New Starts project and its impacts on transit service and ridership. The Study isolates these actual costs and impacts by comparing the conditions that prevail after project implementation to the conditions that existed before implementation.

To accomplish the second purpose - improvements to technical methods and procedures- each Study examines the accuracy of predicted costs and impacts. The Study determines

the accuracy of the predictions by comparing the conditions that prevail after project implementation to the costs and impacts predicted for the project in each phase of its planning and development. Before and After Studies address both purposes through a careful technical analysis undertaken by sponsoring transit agencies in cooperation with other local planning entities and FTA. This arrangement ensures authorship by local agency staff with first-hand knowledge of the project and its development, buy-in of individual project sponsors and the broader transit industry, and consistency with national standards for the analysis.

This paper is intended to serve as an introduction to the B&A Study for major transit capital investments. It begins by establishing the basis for the Study and its overriding goals and objectives. The paper describes the general parameters of the Study, including the data and milestones which apply to all Studies. Finally, this paper summarizes the experiences of several Study sponsors in the earliest stages of the analysis, and reflects upon the challenges they have identified in performing the Study.

Basis for the Study

The Before and after Study has as its basis the *Government Performance and Results Act* (GPRA) of 1993. GPRA requires that Federal agencies improve the effectiveness of their programs and their accountability to the public by focusing on results, service quality, and customer satisfaction. GPRA further requires that Federal agencies improve program management and congressional decisionmaking by assembling objective information about program results and achievement of statutory objectives. The information resulting from each B&A Study will help FTA to meet its GPRA obligation by measuring the impacts of New Starts projects on the communities they serve, in terms of costs and ridership.

As importantly, FTA is requiring the Before and After Study in order to provide a forum for New Starts project sponsors specifically, and the transit industry in general, to “tell their story” i.e. measure the success of fixed guideway capital investments. The Study is further intended to encourage improved practices in data collection, documentation, and analyses of pre- and post- investment transit performance; ensure that the planning and project development process generates reliable information for decisionmaking; provide for “lessons learned” in predicting the impacts of major transit capital investments; accumulate a source of technical information on the actual costs and performance of major transit investments; and enhance FTA’s technical support program by identifying the areas of project planning technical work which might benefit from additional research and guidance. In sum, FTA believes the conduct of B&A Studies for projects receiving or amending future FFGAs will provide for an invaluable repository of information and experience which will benefit the entire transit industry.

The costs of undertaking the Before and After Study are an eligible Federal expense, and may be included in the baseline cost estimate (BCE) of the FFGA. Consequently, agencies undertaking the Study will benefit from Federal financial participation in a comprehensive data collection effort which will be useful for a wide array of local transit

planning and performance monitoring activities. FTA issued draft technical guidance on the Before and After Study in January 2003. This guidance is currently being revised based on the comments and observations of a number of Study sponsors. A final version of the guidance is expected later in the Spring of 2003.

Study Organization

The project sponsor - that is, the entity signing the Full Funding Grant Agreement - is responsible for the design, execution, and reporting of the Before and After Study. Successful completion of the Study will, however, likely require cooperation and coordination among several participants, including the operating agency (if different from project sponsor), the local metropolitan planning organization, the consulting firms engaged in project planning and design, and FTA staff and contractors. The breadth of participants in any B&A Study will be determined by the role of these entities in the planning and development of the New Starts project and their ability to provide information on conditions before and after its implementation.

The December 2000 Final Rule requires that a “data collection plan” be developed by the project sponsor during the final design stage of project development; this plan, which will serve as the scope for the subsequent B&A Study, is later approved by FTA prior to executing an FFGA. FTA notes, however, that the technical work supporting the “predicted” project impacts (in terms of each of the five project characteristics described below) must be documented throughout planning and project development. Consequently, documentation of the methodologies, assumptions, and independent variables used in the planning and development of the project must begin as early as alternatives analysis, and continue throughout subsequent development activities.

FTA believes that the local sponsor has the best understanding of the project and its planning and development; consequently, the details of the Study design, data assembly, and analysis are appropriately left to the sponsoring agency, in cooperation with other local stakeholders. To foster summary analyses of studies across the country, however, FTA has identified several project characteristics and milestones common to all Studies. These common Study attributes are described below.

Study Data

The first element of national consistency is the minimum set of project characteristics that is considered in every Before and After Study. As specified in the December 2000 Final Rule, each Study examines five key project characteristics: physical scope, transit service levels, capital costs, O&M costs, and ridership and revenues. The specific definitions for these five characteristics are:

- Physical Scope – the physical components of the project, including horizontal and vertical alignment, bridges, tunnels, stations, vehicles, right-of-way assembly, and mitigation;
- Transit Service Levels - the frequency, type, and travel times of services on the fixed guideway itself, the frequency and type of other transit services affected by

implementation of the project, and the aggregate level of service provided by the transit system as a whole;

- Capital Costs - the costs of real estate acquisition, vehicle procurement, construction, engineering, management, agency expenses, testing, and start-up;
- O&M Costs - the incremental costs of operating and maintaining both the New Start project and the rest of the transit system; and
- Ridership and Fare Revenues - ridership on the fixed guideway itself, ridership on other transit services affected by implementation of the project, and both ridership and fare revenues on the transit system as a whole.

FTA has identified these five characteristics because of their central roles in the performance of New Starts projects. Capital costs and ridership are typically the most visible numbers associated with each project. Capital costs, O&M costs, and farebox revenues are key elements of the financial plan. Changes in the physical scope made during planning and project development are the most frequently cited source of capital cost changes (as well as the need to amend an FFGA). Overall service levels establish the context for changes in O&M costs and ridership, while service levels on the fixed guideway and feeder buses define the quality of service available to transit riders. Ridership increases represent the magnitude of impacts on congestion and air quality. At local discretion, project sponsors may choose to examine other project impacts as well. Such impacts may include changes in land use policies, land use patterns, transit funding, economic development, special event generators, and operating efficiencies.

Study Milestones

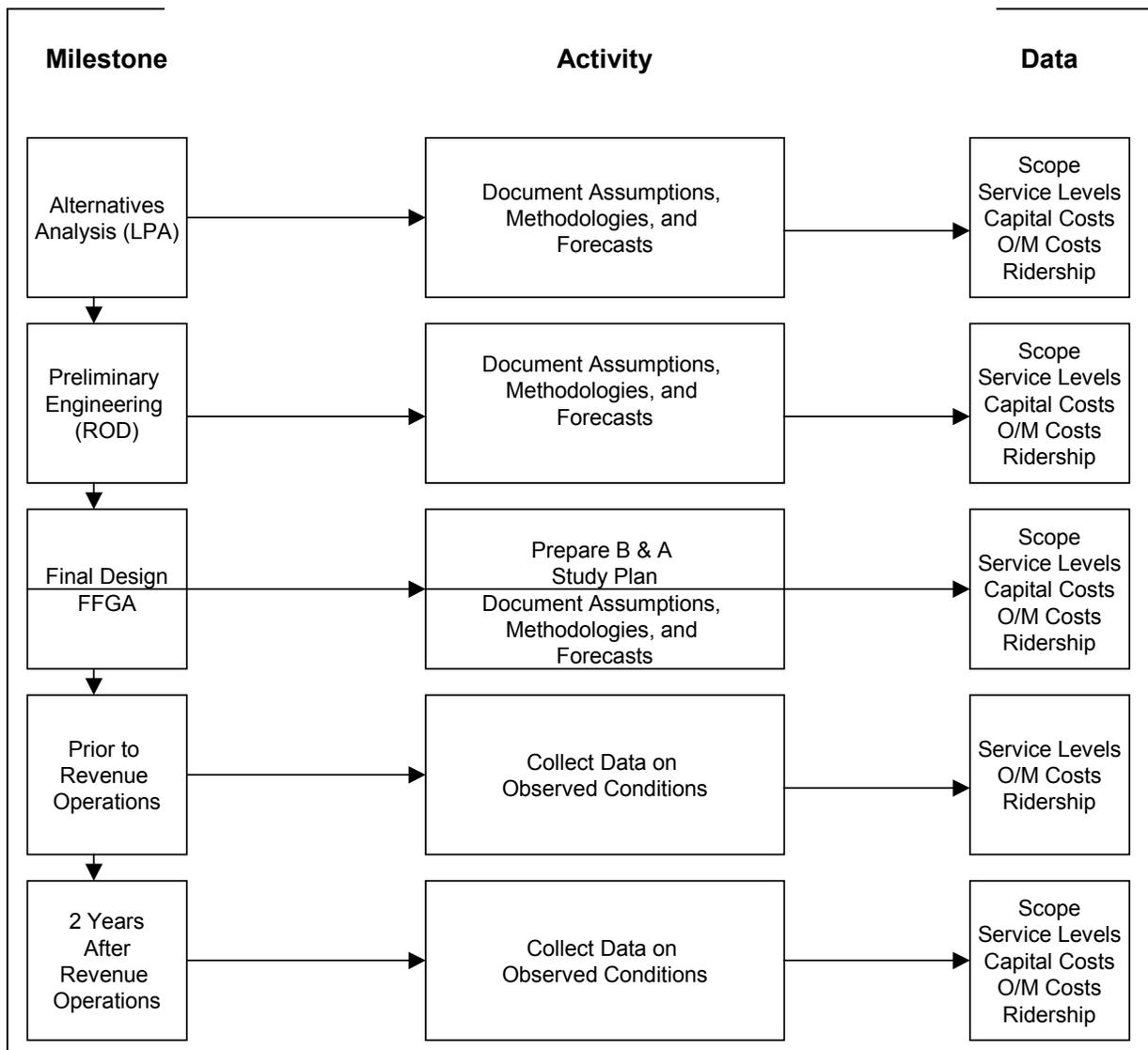
The second element of national consistency is the set of milestones considered by every Before and After Study. As specified by the December 2000 Final Rule, each study considers the five (or more) project characteristics at at least five points in project development, construction, and operation. Three of these milestones are during planning and project development when the predictions were prepared, one milestone is immediately before implementation of the project, and the final milestone is approximately two years after the project opens to service.

- Planning and Project Development Predictions - the forecasts of project characteristics available for decisionmaking are to be documented for three key points in the project development process:
 - the conclusion of alternatives analysis, with the selection of the locally preferred alternative (LPA);
 - the conclusion of preliminary engineering, as signified by a Record of Decision (ROD) or Finding of No Significant Impact (FONSI), pursuant to the National Environmental Policy Act of 1969 (NEPA); and
 - the signing of the Full Funding Grant Agreement.
- Before - the actual conditions are documented that exist immediately before implementation of the project, either just before opening of the project to revenue service or, if construction is likely to introduce major disruptions of transit service and ridership patterns, just before that disruption occurs.

- After/actual - the actual conditions are documented that exist two years after the project has opened for revenue operation.

Data collected or documented for each of these milestones supports the two major elements of the analysis: (1) comparisons of actual conditions before and after project implementation to understand the impacts of the project; and (2) comparisons of predicted and actual conditions to examine the reliability of the predictions. For projects which have amended their FFGAs, the most recent amendment shall serve as an additional data point within the project development milestone. At local discretion, project sponsors may choose to examine information available at other milestones. Figure 1 below graphically presents the milestones and corresponding data collection activities which form the basis of the Before and After Study.

Figure I
Before and After Study Data Collection Process



Analysis

As noted previously, the B&A Study focuses on two main comparisons: 1) conditions prior to implementation of the fixed guideway project versus conditions two years after; and 2) the predicted versus the actual outcomes of the project. In these analyses, capital costs, O&M costs, and ridership patterns of the project after it is built are compared to the predictions and observations of these characteristics made prior to its implementation. Significant variations are identified. In order to explain these variations, the project sponsor tracks changes in the physical scope and the levels of service associated with the project. The project sponsor conducts these analyses as scoped in the Before and After Study plan developed during final design. These analyses will typically involve comparing the actual project characteristics to those that were predicted and to those that were observed before the project was built. Once the comparisons are available the analysis should focus on documenting the forecasts - and the methodologies, independent variables, and assumptions that support them - that have been confirmed by experience and identifying the causes for observed deviations. Analysis of deviations from predicted outcomes will involve review of the data, postulating hypotheses about the causes of forecast error, and assembling information to confirm or refute these hypotheses.

Early Experiences

To date, three agencies have committed to performing a Before and After Study (as envisioned in this paper and described in more detail in the January 2003 draft technical guidance), as a condition of receiving an FFGA for their proposed New Starts project: the Utah Transit Authority (UTA) for its Medical Center Light Rail Transit (LRT) Extension; the North County Transit District (NCTD) for its Sprinter LRT Line between Oceanside and Escondido in northern San Diego County; and the New Orleans Regional Transit Authority (RTA) for its Canal Street Streetcar. A number of other agencies with existing FFGAs which have been amended since the requirement went into effect will also undertake B&A Studies. Five project sponsors proposed for new FFGAs in FTA's FY 2004 budget will soon initiate or are currently preparing Before and After Study plans. Still other sponsors of projects in various stages of development have begun to prepare Study plans.

Agency staff of three Study sponsors – UTA, NCTD, and the Los Angeles County Metropolitan Transportation Authority (LACMTA), which will perform a B&A Study for their Eastside LRT project once its proposed FFGA is executed - were contacted by this paper's authors about the status of their Studies, and, more importantly, their observations about the Study process. Specifically, these individuals were asked the following two questions:

1. What do you see as the major challenges to performing the Study?
2. What do you see as the benefits of the Study, specifically for your agency?

Each individuals' responses reflected their own experience with and observations of the Study, and do not represent any formal agency position. What was desired (and achieved) in the responses to these questions was simply the observations of the technical agency staff most involved in the B&A Study in regards to its analytical challenges, issues, and benefits.

As to the first question, agency staff spoke of a number of challenges to performing the B&A Study. Two of the respondents suggested that the intended rigor of the Study (as outlined in the draft technical guidance), while not being unreasonable, was more effort than they had originally conceived during the development of their original Study plans. Indeed, one individual commented that FTA's issuance of draft guidance *after* preparation of a Study work plan had resulted in several revisions to his project's plan, even as the agency continues the "before" element of the analysis. However, another respondent noted that the *length* of the technical guidance initially suggested a more daunting Study than what the guidance actually presents. Another individual acknowledged the difficulty in locating and assembling the breadth of materials documenting the technical work which supported the planning and development of the project. FTA anticipates that this might be a relatively common occurrence for these first Studies, which are addressing the collection of data pertaining to project predictions well after (in the case of at least one FFGA amendment, nearly 10 years after) they were developed. Conversely, FTA believes that this "challenge" will be eliminated in the near future as New Starts project sponsors "embed" the documentation of all necessary information and variables related to each of the five project characteristics within the project development process.

One Study sponsor expressed concern about the availability of dedicated staff-time (and, by extension, resources) to perform the analysis. Another specific challenge which was identified was the cost and magnitude of a controlled sample on-board survey designed to capture the market stratifications used in the development of project ridership forecasts (trip purpose, origins/destinations, mode of access to the system, income strata, etc.). Transit on-board surveys often are not designed to collect information describing the characteristics of the household in which the rider is resident. When these or similar factors have been used in the travel demand models, the surveys of riders must be appropriately designed so that these travel forecasting related factor are captured.

Two of the respondents further noted the difficulty in ensuring the comparability of data at each milestone required by the Study. Specifically, one individual observed that the tracking of capital costs will be particularly difficult, because of the incomparability of cost categories used in each phase of project development, and because of the significant changes in project scope between the completion of alternatives analysis and the execution of the FFGA. In contrast, the other respondent who commented on the comparability of data noted the long time frame of the study and suggested that as data media evolves (as it has dramatically over the past several years), every effort must be made to ensure "readability" over the course of the analysis.

In addition to challenges, this paper's authors were also interested in the beneficial outcomes of the Study, as perceived by agency technical staff. Everyone who participated in this informal dialogue agreed that the Study results will help them articulate the value and importance of public transportation in their local area. Two respondents shared FTA's objective of using the results of the Study to improve technical methods in project planning. Another respondent indicated that the Study simply reflected "good government," and that a well-designed analysis will be able to demonstrate the return on the public's investment in transit.

Other identified benefits include the capability of measuring the efficiency of bus service ("before") vs. the integration of bus and rail ("after"), as well as quantifying impacts in a way that might attract joint development at and around transit facilities.

Conclusion

The Before and After (B&A) Study has two distinct and important purposes:

- (1) to expand insights into the costs and impacts of major transit investments; and
- (2) to improve the technical methods and procedures used in the planning and development of those investments.

The Study addresses both purposes through a careful technical analysis undertaken by sponsoring transit agencies in cooperation with other local planning entities and FTA. FTA believes the conduct of Before and After Studies on all future FFGAs (and FFGA amendments) will provide for an invaluable repository of information and experience which will benefit the entire transit industry. Several benefits of the B&A Study described in this paper include:

- strengthening the New Starts program by highlighting the successes of individual transit capital investments and the important role that transit plays in improving mobility and the quality of life in communities throughout the Nation;
- identifying and transfer the lessons learned in planning, implementing, and operating transit fixed guideway investments to agencies planning similar projects. Information generated from the B&A Study will enable the sponsors of future New Starts projects to build upon the experiences of past projects, including design and operational features that have proven successful, while avoiding options that have been less successful;
- identifying the strengths and weaknesses in local travel demand forecasting and capital and O&M cost estimating procedures, and provide insight into how technical methods can be improved to support decision making for future projects;
- "embedding" data assembly and analyses which measures predicted and actualized project costs and impacts into the project planning and development process;
- accumulating a source of technical information on the actual costs and performance of major transit investments.

The Before and After Study requirement is relatively new, and current and future Study sponsors acknowledge a number of challenges with it. However, through the finalization of FTA's technical guidance on the Study and the evolving experience of New Starts project sponsors in its conduct, the authors of this paper believe these challenges will be met and that the B&A Study will provide for the array of benefits described herein.

TMIP at 10: Envisioning the Future of the Travel Model Improvement Program

Michael Culp and Brian Gardner, *Federal Highway Administration*

Abstract. The Travel Model Improvement Program (TMIP) was created in 1992 to improve travel forecasting tools used by transportation and air quality planners. The program created tracks of activity that focused both on making incremental improvements to the existing travel forecasting procedures, and on completely redesigning the travel forecasting process. Over the past year, TMIP has developed a new vision that balances technology development and deployment with training technical assistance and outreach to model users. The program also broadens its emphasis from travel forecasting to include related areas such as data collection, land use forecasting, GIS, safety and security analyses.

TMIP Goal 1 - Building the capacity of planning agencies: TMIP has set a goal of helping planning agencies build their institutional capacity to perform better technical analyses. The program will continue its training, technology transfer, and clearinghouse activities. TMIP is also initiating several new programs, including a peer exchange and review program. In addition, TMIP plans to develop and deliver training on techniques such as activity-based demand estimation and land-use forecasting.

TMIP Goal 2 - Improving technical tools: As TMIP continues to work on TRANSIMS technology, the program has initiated several new projects, including the development of better techniques for time-of-day commercial travel modeling. TMIP will develop a research needs assessment in the next year, to help direct and prioritize research topics.

TMIP Goal 3 - Ensuring the quality of planning technical analysis: TMIP has begun several projects focused on assuring the quality of travel analyses. With the help of key stakeholder groups, TMIP has initiated an effort to develop travel-forecasting guidelines for air quality analysis. The program has also initiated a training effort to help Federal field staff understand more about travel forecasting procedures, and its implications and limitations for use in air quality analysis.

The Journey to MPO Formation: That was then, this is now.

Robin Mayhew, AICP, *Federal Transit Administration*

Abstract. In the May 1, 2002 Federal Register, the US Bureau of the Census issued the designations for new urbanized areas (UZA). UZAs are defined as areas with a population of at least 50,000. This designation triggers a Federal transportation planning requirement that the Governors and local officials establish new MPOs within twelve months of designation or integrate into an existing MPO. As occurred in response to the 1990 Census designations, the Year 2000 Census has identified new UZAs. Local planning partners in these UZAs must, in turn, decide to either form new free-standing MPOs, or affiliate with an existing MPO if one is adjacent.

This proposed session would provide information from a recent case studies project, funded by FTA in coordination with FHWA. The case studies provide local accounts of the initial steps in the MPO formation process from 10 newly formed MPOs subsequent to the 1990 Census. FTA will provide an overview of salient points from the case studies.

Specifically, the areas covered in the case studies include:

- Administrative Logistics - Financial Support and Staffing
- Working with Public and Local Officials
- Policy Board Membership
- Equipping for Technical Analysis and Support

TAPS: A Customizable Transportation Automated Prioritization Software and Evaluation Methodology to Score and Rank Thoroughfare System Improvements

Edith B. Ngwa, Ph.D, *Dallas County Public Works*; Kurt Schulte, AICP, *Kimley-Horn & Assoc.*; and Isela Rodriquez, *Dallas County Public Works*

Abstract. Each year, local governments are faced with the immense challenge of judiciously allocating a limited number of resources to an inexhaustible list of needed services and infra-structural improvements. In no sector is this appropriation more challenging than in transportation planning. A Capital Improvement Program (CIP) has traditionally been utilized by most cities/counties as the vehicle for prioritizing roadway improvements. For some, the CIP is defined by a well-documented, formal, and objective evaluation/prioritization methodology and process, while for others, especially small cities with limited technical staff, the process of prioritization is left to the subjective judgement of elected officials at best and inexperienced staff at worst.

How should one embark on the process of developing a CIP program for roadway improvement that is fully reflective of their jurisdiction/region's financial, environmental and transportation priorities? How should proposed improvements be scored and ranked under such a program? What factors, (traffic and non-traffic-related) should be included in the rating system/ evaluation methodology? What, if any, new technology tools should be utilized to automate the scoring and ranking process? Should one rely on technical evaluation results alone for final decision-making?

This paper will endeavor to answer the above questions by focusing on the experiences and lessons-learned by a large and predominantly urban county in deploying an innovative annual "pay-as-you-go" CIP program to prioritize its thoroughfare system improvement. The paper will begin by describing the unique collaborative process that went into formulating and refining the CIP evaluation methodology. It will then focus on the evaluation methodology itself, describing in full, the ten factors, (both traffic and non-traffic-related) that provide the backbone of the methodology and the reasons (both technical and non-technical) why some factors were selected and why others were later recommended for exclusion. The paper will also describe TAPS—the Transportation Automated Prioritization Software—developed to score and rank proposed improvement projects. It will delve into detail on how this software program operates, describing the required inputs, outputs and user actions required to run the program. The paper will then conclude by enumerating lessons-learned in the County's 3rd year of utilizing the methodology and software program and suggest methods for further improvement of both.

Pairwise Comparison Method for Evaluation of its Investments

Huey P. Dugas, *Capital Region Planning Commission*

Abstract. This paper addresses the issue of measuring the benefits and effectiveness of Intelligent Transportation System (ITS) devices. It demonstrates a technique for comparison of the benefits of specific ITS systems relative to one another and relative to the stated objective of a particular device. It also shows that by comparing the benefits, and costs of ITS to capacity projects each can be deployed in a more efficient and effective manner. In order to determine the relative benefits and effectiveness of the individual ITS devices, the method of pairwise comparison (PWC) was used. This method was also used to evaluate five ITS Goals for Baton Rouge against each other so that the Goals could be prioritized and ranked. Once the Goals were ranked and prioritized five ITS devices were evaluated in a pair-wise fashion relative to each goal. In this way, the weight or priority of each device was allowed to vary according to the specific Goal under consideration.

The PWC method is considered as a project evaluation process. Like other project evaluation processes it starts by identifying project goals and objectives. It further identifies criteria and measures of effectiveness. The criteria measures demonstrate the performance of the system under study for different scenarios. PWC needs no explicit assumptions of the criteria's weights. The method generates the weights mathematically, and adds to the objectivity of the technique. PWC is used for ranking alternatives and criteria. It requires the judgement of experienced people. Expert judgement was obtained from a panel of judges. In this case a panel of experts was formed from professionals engaged in traffic engineering or transportation planning. Alternatives were listed against each other in a matrix. Generally, since the values of comparison are derived from a group of experts providing their judgement for evaluation, and not all judgements are transitive and consistent, there must be an approach to measure this degree of inconsistency in judgement. This measure is referred to as an Inconsistency Index. The Inconsistency Index is compared to a statistical tabular value called a Random Index (R.I.). The degree of inconsistency is derived from the value of the ratio of the Inconsistency Index to the Random Index. The closer the ratio of I.I./R.I. is to R.I. the less consistency there is in judgement. The results of this research project demonstrate the high degree of consistency produced by the panel of judges.

This paper presents the results of a pair-wise comparison of proposed ITS investments in Baton Rouge. Through the application of this procedure the author was able to demonstrate that ITS devices can be prioritized on an overall basis, against each other, and each specific ITS goal. This paper also includes a discussion of the basic theory of the pair-wise comparison process, the Inconsistency Index, and its application for comparison of relative ITS benefits.

Project evaluation is one of the most important stages in the transportation planning process. The objective of this paper is to describe the pairwise comparison (PWC) evaluation methodology and its application to the Baton Rouge area for Intelligent Transportation System ITS evaluation. The study area for this project consisted of the Baton Rouge metropolitan Planning Organization (MPO) study area. This area includes parts of the parishes of East Baton Rouge, West Baton Rouge, Livingston and Ascension. These parishes straddle the Mississippi River and include an area of 600 square miles, with a population of approximately 600,000. During the 1990s Baton

Rouge engaged in an aggressive effort to implement ITS infrastructure. This includes an Advanced Transportation Management Center of over 55,000 square feet, and almost all ITS field devices discussed in this paper. Additionally, Baton Rouge is deploying a field communications system that transmits information from the field devices to the ATMC and vice-versa. Also, traffic engineers in the Center can communicate and control all ITS devices in the field. On top of that, the ATMC houses a complete complement of dispatch personnel and equipment, to include fire, police, 911, EMS, and emergency operations. All of this technology became operational in October 2001, after starting design in 1998. The breadth, depth and pace of this endeavor is truly remarkable. The impetus for the strong effort to pursue ITS strategies for development in Baton Rouge was its EPA designated air quality status as a “serious” non-attainment area for ozone. Congestion Mitigation for Air Quality (CMAQ) funds were and still are available to the Baton Rouge MPO for implementation of certain transportation improvements. Capacity improvements are denied the use of these funds, but development of ITS related projects is encouraged.

Still a problem lingers. Suppose the funds to engage in the development and deployment of ITS projects in a place the size of Baton Rouge would be insufficient for design, construction and deployment on this scale. In that case, extremely serious choices would have to be made. A smaller ATMC would have to be designed and built, or possibly space would have to be utilized where available in some existing structure. And certainly not all ITS devices would be deployed. Likewise, communication systems in the field would not consist of “fibre optics” and microwave systems. Possibly some form of slower and more limited capacity medium such as high speed (but slower than fibre optics) telephone service would suffice. Given this scenario, which is likely in the near future (if it is not here already), there has to be methods and techniques that allow decision makers to evaluate alternatives and prioritize on the basis of scarce and limited resources.

Pairwise Comparison Methodology

The PWC method is considered as a project evaluation process. Like other project evaluation processes it starts by identifying project goals and objectives. It further identifies criteria and measures of effectiveness (MOE). The criteria measures demonstrate the performance of the system under study for different scenarios. Project evaluation processes are beset with certain problems. These include conflicting objectives and uncertainty of impact estimation. The latter includes numerous impacts such as, a mix of socio-economic groups affected by a project, some impacts are quantifiable while others are not, and the scale and units of impact differ by alternative. The technique used in this paper overcomes these obstacles to successful project evaluation.

Table 1 - ITS America's National ITS Deployment Goals and Objectives

ITS Goals	Objectives Associated with Goal
Improve Safety	Reduce the number of motor vehicle collisions, associated injuries and fatalities Improve the response time of emergency medical services Improve the ability to handle HAZMAT incidents Enhance traveler security and road service responsiveness
Increase Efficiency	Increase efficiency by smoothing flows Increase average vehicle occupancy Increase capacity of existing facilities Reduce vehicle miles traveled Reduce time lost in intermodal interchange Reduce delay associated with congestion
Reduce Energy and Environmental Impact	Reduce harmful emissions per unit of travel Reduce energy consumption per unit of travel Reduce right-of-way requirements and community disruption Reduce fuel wasted Enhance efforts to attain air quality goals
Enhance Productivity	Reduce cost incurred by fleet operators Reduce cost and improve equity of fee collection Reduce delays and cost of regulating vehicles Reduce cost and improve quality of data collection Reduce travel time Reduce cost to transportation-dependent industries
Enhance Mobility	Improve accessibility to intermodal transportation Improve quality of travel options information Improve mode choice options Improve travel time predictability Reduce travel stress

Source: (14)

The PWC method can also be classified within a group of techniques used to evaluate and compare transportation projects. The three main categories are elementary, economic analysis, and comprehensive or multi-objective. The PWC method is a comprehensive or multi-objective technique. It needs no explicit assumptions of criteria's weights. The method provides or generates the weights mathematically, and adds to the objectivity of the technique. Similar to other project evaluation techniques, it has certain areas of sensitivity. It is sensitive to data availability, the availability of time for evaluation, resources committed to the project, project cost, and project political requirements.

This paper compares ITS devices to each other, and to ITS Goals and Objectives for the Baton Rouge area. These Goals and Objectives were provided by the ITS Early Deployment Study conducted by URS Greiner Consultants under contract with FHWA, LDOTD and the Baton Rouge MPO. This study is often referred to as the ITS Master Plan for Baton Rouge. See

reference 14. The ITS Goals and Objectives for Baton Rouge were based on ITS America’s Goals and Objectives. The Goals are to improve safety, increase efficiency, reduce energy and environmental impacts, enhance productivity, and enhance mobility. Each Goal has several related Objectives. The Goals and Objectives are included in tabular form and shown as Table 1 above.

In order to determine the relative benefits and effectiveness of the individual ITS devices, the method of pairwise comparison (PWC) was selected. This method was also used to evaluate the Goals against each other so that the Goals could be prioritized and ranked. Once the Goals were ranked and prioritized the ITS devices were evaluated in a pairwise fashion relative to each goal. In this way, the weight or priority of each device is allowed to vary according to the specific Goal under consideration.

PWC is used for ranking alternatives and criteria. It requires the judgement of experienced people. Alternatives are listed against each other in a Matrix called A. Each alternative in a row of the matrix is compared to another alternative on the same row. This comparison takes place two at a time on a row until the alternatives are exhausted. The comparison value used is a quantity proportional to the degree that alternative i dominates alternative j. This process is repeated for all cells in the upper triangle of Matrix A. The diagonal of the Matrix is filled with 1’s. See Table 2 below.

Table 2 - ITS Goals Comparison Matrix

Goals	Safety	Efficiency	Mobility	Energy/Env.	Productivity
Safety	1				
Efficiency		1			
Mobility			1		
Energy/Env.				1	
Productivity					1

Values below the diagonal are filled with the reciprocals of the upper triangle. This Matrix, referred to as the Judgement Matrix, is then transformed to a Vector of priority weights **w**. This step uses the same method used to determine the weights for criteria. The numbering system used to compare the importance of pairs of alternatives is referred to as the “importance scale”.

Table 3 shows the numbering system used in this experiment.

Table 3. Interpretation of Values in Pairwise Comparison Matrix

Value of a(ij)	Interpretation
1	Objectives i and j are equally important.
3	Objective i is slightly more important than j.
5	Objective i is strongly more important than j.
7	Objective i is very strongly more important than j.
9	Objective i is absolutely more important than j.

Two mathematical assumptions underlie the PWC method. They are the principles of transitivity and consistency of judgement. Transitivity can be accounted for by the comparison of three alternatives called **c1**, **c2** and **c3**. If **c1** is more important than **c2**, and **c2** is more important than **c3**, then **c1** must be more important than **c3**. Likewise, if **c1** is **r** times stronger than **c2** and **c2** is **s** times stronger than **c3** then **c1** is **r x s** times stronger than **c3**. These assumptions lead to the values in the lower triangle of **A**, forming the inverse of the upper triangle in the same Matrix. The second assumption relates to the principle of consistency. It is possible to measure the degree of inconsistency in PWC analysis. Since the values of comparison are derived from a group of experts providing their judgement for evaluation, and not all judgements are transitive and consistent, there must be an approach to measure this degree of inconsistency in judgement. This measure is referred to as an Inconsistency Index. Eigenvalues and Eigenvectors are the basis for calculations in PWC analysis. The mathematical formula used in determining the Eigenvalues and Eigenvectors is as follows.

$$Aw = \lambda_{\max} w.$$

The formula for the Inconsistency Index (I.I.) is as follows.

$$. \lambda_{\max-n} - n) / (n-1).$$

The Inconsistency Index is compared to a statistical tabular value called a Random Index (R.I.). The degree of inconsistency is derived from the value of the ratio of the Inconsistency Index to the Random Index. The closer the value of this ratio is to zero, the greater the consistency in judgement. The closer the ratio of I.I./R.I. is to R.I. the less consistency there is in judgement.

There are several methods used in calculating priority weights. Four known methods are based on some form of taking the average of columns or rows and normalizing. A fifth method is the only exact method and is obtained by calculating the normalized principal Eigenvalue by raising the judgement Matrix **A** to some high power.

One cycle of the PWC method is executed to compare the multiple goals or objectives of the project. This produces a Vector of criteria weights. Additional cycles of calculations are conducted to compare ITS devices to each other, using one goal for reference at a time. See Table 4.

Table 4 - ITS Device Comparison Matrix

ITS Device	Camera	Detector	VMS	Signal Synchronization	Ramp Metering
Camera	1				
Detector		1			
VMS			1		
Signal Synchronization				1	
Ramp Metering					1

A following cycle of comparison is made to condense the above Matrix results to one Vector for each criterion. This is accomplished by performing a matrix multiplication of the first Matrix by the Vector of weights. This step results in a final or overall ranking of weights.

Experimental Design

Expert judgement is obtained from a panel of judges. In this case a panel of experts was formed from professionals engaged in traffic engineering or transportation planning. Twenty individuals were surveyed. Sixteen responded to the survey. Two were from Transportation/Civil Engineering faculties from two universities. Nine were from transportation engineering consulting, one was from the field of transportation engineering research at the Texas Transportation Institute (TTI), four were from local government traffic engineering services. Information transmitted to the survey panel included the numbering system representing the intensity scale with definitions, the ITS Goals and Objectives for the Baton Rouge ITS Early Deployment Study (ITS America source), and a spreadsheet of six blank matrices. One matrix contained five goals across the columns and these were repeated across the rows. The goals were safety, mobility, efficiency, energy/environmental, and productivity. The following five matrices included five ITS devices across the columns and these were repeated across the rows. This format was repeated for the following five matrices. However, each matrix pertained to one of the five Goals. These matrices were completed by the panel and returned to the authors via fax or email. These results were combined into one matrix representing the group's evaluation. All computations were executed on the group evaluation. The Matrix of Goal evaluation with the diagonal as 1's and the reciprocals in the lower triangle is shown as Table 5.

Table 5 - Pairwise Comparison of Goals

Goals	Safety	Efficiency	Mobility	Energy/Env	Productivity
Safety	1	3	3	5	3
Efficiency	1/3	1	3	5	1
Mobility	1/3	1/3	1	1	1
Energy/Env.	1/5	1/5	1	1	1
Productivity	1/3	1	1	1	1

Results

The results of the calculations for the Goals Matrix are shown in **Table 6**. That table shows the list of ITS devices, the raw Eigenvector values and the normalized values. The table also shows Safety ranks as the most important Goal, followed by Mobility and Efficiency. One example for the five ITS devices measured against the Goal of Safety is shown in **Table 7**.

Table 6 - Priority Vector with Respect to Goals

Goals	Eigenvector	Normalized
Safety	.811	.417
Efficiency	.335	.172
Mobility	.367	.189
Energy/Environment	.182	.094
Productivity	.249	.128

That table shows the same type of information as in the previous table. It also shows that Cameras are the most important device if Safety is the Goal. With respect to relative importance, Cameras are followed by Variable Message Signs (VMS), Road Detectors and Signal Synchronization.

Table 7 - Priority Vector of ITS Devices with Respect to Safety

Device	Eigenvector	Normalized
Camera	.852	.476
Detector	.231	.129
VMS	.421	.236
Signal Synchronization	.184	.103
Ramp Metering	.100	.056

Table 8 shows all priority Vectors for each of the devices. It is already apparent that cameras stand out as the most important ITS device only for the Goal of Safety. It is clear that the ITS device of Signal Synchronization dominates for the remainder of the Goals.

Table 8 - Priority Vectors for each Device and Goal

ITS Device	Safety	Efficiency	Mobility	Energy	Productivity
Camera	.476	.122	.108	.156	.244
Detector	.129	.174	.105	.218	.105
VMS	.236	.241	.155	.144	.111
Signal Syn	.103	.409	.504	.393	.491
Ramp Met	.056	.055	.128	.088	.050

Finally, through further matrix calculations it is possible to obtain an overall priority Vector. By combining all Goals and Devices it is possible to obtain the overall priority Vector. **Table 9** repeats the priority Vectors for the five devices for each of the Goals, and adds the overall priority vector. It is shown as the first column of vectors shown on the table.

Table 9 - Priority Vectors for each Device, Goal and Overall

ITS Device	Overall	Safety	Efficiency	Mobility	Energy	Productivity
Camera	.286	.476	.122	.108	.156	.244
Detector	.138	.129	.174	.105	.218	.105
VMS	.197	.236	.241	.155	.144	.111
Signal	.308	.103	.409	.504	.393	.491
Ramp	.071	.056	.055	.128	.088	.050

The decimal numbers in Table 9 are converted to their rank numbers, in order to make it easier to read the importance of each ITS device relative to each Goal. On an overall basis, given that resources are adequate to address all Goals and to install and operate all devices, it is demonstrated that Signal Synchronization is the most important. This is followed by cameras, variable message signs, road detectors and ramp metering, respectively.

Table 10 shows the rank of each device by each Goal and Overall. The most striking feature of these ranks is that Signal Synchronization ranks first for four of the Goals as well as overall. Cameras rank first under the Goal of Safety. Other changes in rank for each device are shown on the same table.

Table 10 - Ranking for Each Device by Goal and Overall

ITS Device	Overall	Safety	Efficiency	Mobility	Energy	Productivity
Camera	2	1	4	4	3	2
Detector	4	3	3	5	2	4
VMS	3	2	2	2	4	3
Signal	1	4	1	1	1	1
Ramp	5	5	5	3	5	5

Finally, the Inconsistency Index was calculated for all priority vectors. The largest Eigenvalue of a matrix is the Principal Eigenvalue referred to as λ_{\max} of Matrix A. The value of λ_{\max} is usually close to the value n. In this case n = 5. Table 11 shows the values for λ_{\max} , I.I., the ratio I.I./R.I. and the relative distance of each ratio from zero. The Random Tabular value for this experiment is 1.12. Since the ratios of I.I. to R.I. are considerably below this value, it is obvious that all values confirm strong consistency in judgement by the panel of experts.

Table 11 - Consistency Evaluation for PWC

Item	λ_{\max}	I.I.	I.I./R.I.	% from 0
Goals	5.640	.806	.720	64.3
Safety	5.820	.205	.183	16.3
Efficiency	5.929	.232	.207	18.5
Mobility	5.507	.127	.113	10.1
Energy/Env	5.627	.157	.140	12.5
Productivity	5.508	.127	.127	10.1

Conclusions

The comparison of alternatives is an important part of the decision making process in the field of transportation planning. This paper has shown that pairwise comparison method is a powerful tool that can be used in project evaluation. Most project evaluation methods can only be applied to quantifiable benefits and costs. Likewise these elementary methods deal with one value to make a decision, such as a benefit cost ratio, rate of return, net present value, or annual worth. One of the main advantages of this technique is the ability to handle comprehensive or multiple objectives, thereby showing the degree of achieving every objective by every alternative. The effectiveness values of the pairwise comparison method can be combined into one value for each value, which in turn, determines the priority of each alternative. PWC does this mathematically and is therefore completely objective. It requires no explicit assumptions about criteria weights since these are derived by the method.

This paper has shown that of the five Goals for ITS, safety was the most important. This was followed by mobility, efficiency, productivity and energy/environment. If safety were the only goal, the most important ITS device is the camera, followed by variable message sign, roadway detectors, signal synchronization and ramp metering. On an overall basis, with all goals considered simultaneously the ranking of the devices are signal synchronization, cameras, variable message signs, roadway detectors and ramp metering. The Consistency Index was calculated for all priority vectors. The largest Eigenvalue of a matrix λ_{\max} of Matrix A. It was also shown that by comparing this value to a tabular value of random numbers, a measure of the degree of consistency in expert judgement is obtained. It was shown by calculating Consistency Index values for this research project that there was strong consistency in judgement by the panel of experts.

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Analysis of User Benefits Results: Findings and Observations

Eric Pihl, *Federal Transit Administration*

Abstract. The denominator of FTA's cost-effectiveness measure has recently been replaced by a measure that quantifies hours of system-wide user benefits. This approach relies on estimates of benefits, or utility, that accrue to all transportation system users. Travel demand models include the attributes and characteristics important for travelers in making modal decisions, and this information is useful in establishing a systemwide measure of consumer welfare.

The new measure offers significant advantages over the previous measure, which was based on the ratio of incremental cost to incremental rider in the forecast year. Although fairly simple to compute, the previous measure failed to account for benefits accruing to existing riders through transit service improvements. This limitation is particularly pronounced when transit already has high market penetration in a given corridor. The new measure is sensitive to the full range of attributes that are used to characterize the "attractiveness" of transportation models. The measure offers an additional advantage of providing internal consistency between travel demand model results and cost effectiveness calculations.

While the concepts that underlie this approach have been incorporated in travel demand models for many years, the relationship between previous measures based on new riders and a revised measure based on "hours" of benefits is not well understood. This presentation will identify and describe the characteristics of transportation alternatives that are likely to produce positive user benefits, and the markets in which system benefits are likely to accrue. A synthesis of examples from a variety of locations nationwide will provide insight into the nature and magnitude of user benefits across a variety of transportation system improvements. The examples will be drawn from criteria developed from FTA's most recent New Starts report.

Introduction to the Census Transportation Planning Package

Celia Beortlein, *US Census Bureau*

Abstract. The Census Transportation Planning Package (CTPP) is a set of special tabulations designed for transportation planners from the decennial census. CTPP 2000 is sponsored by the State Departments of Transportation under a pooled funded arrangement with the American Association of State Highway and Transportation Officials (AASHTO). CTPP contains tabulations by place of residence; place of work; and for flows between home and work. What makes CTPP unique is that it is the only Census product that summarizes data by place of work and provides information on the travel flow between home and work. It is also the only source of information provided by the Census Bureau with summary tabulations available for Traffic Analysis Zones (TAZs) and other small geographic areas.

The CTPP 2000 data access tool (CAT) is being developed as a user-friendly program to extract data. My portion of the presentation in Baton Rouge was to demo the Beta-version of that tool. It allows the data user to choose tables by topic area. Point + click row and column summaries, GIS for data query and mapping, ability to export data to database formats, techniques for output data to GIS useable formats were all demonstrated.

A New Angle to Learning – The CTPP Electronic Guidebook

Ed Christopher, *FHWA Midwest Resource Center*

Abstract. In this presentation a brief status report of the Census Transportation Planning Package (CTPP) was presented, where it is in the production process and when the States and MPOs could expect to see their data. The CTPP is a special tabulation of the Census journey-to-work data for the transportation planning community. In addition to providing the update a new learning tool was also debuted. The Federal Highway Administration has been preparing a CD-ROM based tool, called the "electronic guidebook". The Guidebook is a training device designed to assist both seasoned and novice CTPP users. The information of the CD is presented using Quicktime software and will run on just about any computer. It is chock full of information on how to work with and understand the various aspects of the CTPP. There are five "learning modules" as well several case studies puts the user in the seat of a transportation planner to use the data to solve "real world" problems. The CD beta version is currently being distributed with the final copies to be released late in the summer of 2003. Copies will be widely distributed and Beta versions can be acquired by contacting Nanda Srinivasan at nanda.srinivasan@fhwa.dot.gov or by calling 202-366-5021.

Census Data in the MPO

Bob Paddock, *Metropolitan Council*

Abstract. This presentation focuses on how a Metropolitan Planning Organization (MPO), whose responsibility is to oversee the orderly growth and development of an entire urban region, utilizes Census-based information in its operations. In this example, the focus is on the MPO for the Minneapolis-St. Paul metropolitan area. As a preamble, the presentation examines the overall responsibilities of a number of metropolitan areas around the country and how these responsibilities are realized through the use of census information.

In a closer observation of the Minneapolis-St. Paul region, we see how successive use of census “journey-to-work” tabulations over the past decades (1970, 1980, 1990) are being intermeshed with the most recent year-2000 figures to help determine trends in sprawl, travel times, mode useage and trip interchanges. From this set of information, the MPO can ascertain how effective its regional policies have or have not performed over time, and whether or not changes are needed. Among the findings is a realization that the effects of extensive urbanization are reaching beyond its jurisdictional responsibility. The question here is: Now what?

A Walk through Time – A Look at the Journey-to-Work Trends

Nancy McGuckin, *Travel Behavior Consultant* and Nanda Srinivasan, *Cambridge Systematics, Inc.*

Abstract. This presentation explores the changes in commute characteristics of U.S. workers by looking at the last forty years of data from the U.S. Decennial Census. Some of the changes that impact commuting trends are:

- Changes in family structure and workforce composition,
- Growth in area, population, and workers in suburban counties of major MSAs,
- Large increases in households with multiple vehicles, and
- Increases in private vehicle use and significant increases in commute times.

The presentation examines all of these variables and concludes that Americans moved to private vehicle use during the suburban housing/workplace boom in the 70s and 80s. Women's entry to the workforce, the decline in household size, and the increased vehicle availability all impacted the mode shift. In the 1990s the census showed large increases in travel time to work, and we expect to see shifts in time of departure and peak spreading as a result.

The Promise and Pitfalls of Mixed Logit Models

Joan Walker, Ph.D., *Caliper Corporation*

Abstract. Discrete choice models form the building blocks of disaggregate transportation demand models. In the beginning, the primary tool was the logit model and the primary application was mode choice. Over the years, two transformations have occurred: first, the nested logit model has become widely adopted, and second, discrete choice models have been introduced into all levels of the transportation demand modeling process (auto purchases, activity and travel scheduling, departure time choice, route choice, recreational travel decisions, housing decisions, etc.). The heir apparent in this progression of discrete choice models has arrived in what is called the *mixed logit* (or logit kernel) discrete choice model.

Mixed logit is simply a logit model with the addition of flexible disturbances. This formulation is powerful, because it is both (1) tractable and (2) able to resolve numerous limitations of logit and nested logit. One example of its flexibility is that mixed logit relaxes the Independence from Irrelevant Alternatives (IIA) property by allowing unrestricted substitution patterns. So, unlike in nested logit, an alternative can belong to more than one nest – perhaps carpooling is associated with *both* the auto nest and the transit nest. Another property of mixed logit is that it allows for (random) taste heterogeneity among travelers, such as different time and cost sensitivities. Introducing such heterogeneity in the model can lead to significantly different forecasts. Rich properties such as these along with advances in computational power, advances in simulation techniques, and availability of estimation software has led to a proliferation of mixed logit models in the transportation literature.

This talk will present the technique (what, why, and how), and discuss the advantages, drawbacks, and practical issues of using mixed logit. Empirical results from a mode choice model will be used to compare the multinomial logit, nested logit, and mixed logit formulations (including a discussion of behavioral assumptions, computational time, biases in the parameters, and impacts on forecasts).

MPO Travel Demand Modeling Requirements Survey

Tom Walker, *DVRPC* and Fred Abousleman, *NARC*

Abstract. The US Congress is now considering transportation, air quality, and other related legislation that may impact the modeling requirements associated with Metropolitan Planning Organization's (MPO) transportation, land use, and air quality planning activities. This paper reports the results of a travel demand modeling survey of the National Association of Regional Councils (NARC) membership, done in conjunction with the Delaware Valley Regional Planning Commission (DVRPC). This survey collected information on:

- 1) The current state of practice in land use, travel demand, and air quality modeling among MPOs, including their degree of compliance with existing TEA 21 modeling requirements;
- 2) The current plans of MPOs for model validations/recalibrations and upgrades; and
- 3) The perceived need to define and coordinate best modeling practices and MPO interests with upcoming Federal and State modeling legislation and policies.

This paper presents summaries of current MPO transportation and land use modeling practices and improvement plans, air quality modeling, conformity procedures, and other modeling topics. A discussion of MPO current modeling practices, upgrades to achieve best modeling practices, and upcoming legislation follows the presentation of the survey results.

Executive Summary

The National Association of Regional Councils (NARC), in conjunction with the Delaware Valley Regional Planning Commission (DVRPC), conducted a national survey of Regional Councils and MPOs to ascertain current modeling practices, planned upgrades, and the related costs for model enhancement, maintenance, and validation. The survey included three aspects of modeling required by the ISTEA and CAAA legislation: socioeconomic and land use projection, travel demand forecasting, and mobile source emissions calculation.

The response to the survey was very good, including 31 planning organizations. It includes almost all of the large MPOs and a good cross section of medium and smaller regional agencies. The survey results, together with emerging planning needs and advances in the information science and modeling methodology, have been used to develop recommendations for inclusion in the next transportation bill now under consideration by the Congress.

Most urban regions of the United States face relentless continuing growth in highway travel volumes as a result of population and employment growth. Decentralization of land use patterns into auto-oriented suburban and rural areas also plays a role, as do demographic shifts, increases in auto ownership, and other causes. The urban travel demand forecasting models are, and will continue to be, an integral part of the planning establishment in all urban regions in the US. As the urban fabric of the US matures into an auto-oriented development pattern, transportation infrastructure capacity expansion is increasingly difficult from the financial, legal, and environmental impact standpoints. The models are very important in optimizing and legitimizing planning efforts and resolving related disputes. Lawsuits related to proposed transportation projects are very common. Issues related to the adequacy of the travel forecasting models used in planning stages are central to the legal arguments and often pivotal in the decision. Projected uses of the models can be categorized into five interrelated areas:

- New transportation facility construction and the expansion of existing facilities
- Land use planning and growth management
- Travel demand management
- Economic and environmental justice
- Environmental concerns and air quality planning

It is very clear that the travel demand models and related land use and emissions estimation procedures will continue to be most important elements in regional transportation and environmental planning activities. The new transportation bill should make explicit provisions for the validation and maintenance of regional models and for required upgrades. These enhancements are needed to remain consistent with acceptable modeling practice and to address emerging transportation planning issues. Suggested guidelines for this legislation follow:

1. *Adequate funding for routine model validation, maintenance, and enhancement should be provided.* There is a very large difference between smaller (populations less than 500,000) and large MPO=s planned expenditures. On average, smaller MPOs plan to spend \$220,000 per year on land use, transportation, and mobile source emissions models and large MPOs plan to spend \$780,000. One should remember, when interpreting these cost figures, that these are rough estimates that can vary significantly from one MPO to another, depending on the local situation and the character of upgrades that are planned. In aggregate, these planned expenses are comparable to historical spending rates over the last 10 years. These expenditures are necessary to sustain MPO modeling capabilities at the current level. There is variation in planned expenditures between large and very large MPOs. The average transportation model expenditures for MPOs with regional populations over four million is about 25 percent higher than the average for all large MPOs. This planned spending, for the most part, reflects required model validations and incremental improvements to the models and related software.

2. *MPOs should be given flexibility to tailor their modeling processes to local planning issues and requirements.* Land use and transportation modeling requirements should reflect the local planning culture in terms of transportation issues, data availability, and the current specification of the models.

3. *Detailed model specification issues should not be addressed in the legislation.* The travel modeling community is served by an active academic and professional community that can assist in the determination of acceptable practice.
4. *If new transportation planning initiatives not adequately addressed by regional models are included in the bill, funding for the required model upgrades should be provided.* Modeling of congestion pricing and other aggressive demand management policies, TRANSIMS and so forth may require extensive and expensive upgrades to the existing MPO models. Specific funding must be provided in the bill, if extensive model upgrades are mandated.
5. *Model requirements, such as validations, should be coordinated with the availability of Census and other survey data.* This will improve the efficiency of the conformity process and improve the quality of the results by eliminating the need for interim year validation forecasts.
6. *Specific provisions should be made in the bill to provide technical resources for MPOs who are placed in a non-attainment status as a result of the 8-hour air quality standards.* For smaller MPOs, this conformity demonstration support, in many cases, may be provided by state environmental protection and transportation departments as an adjunct to the SIP development process. Special situations may also exist where individual large MPOs might need to upgrade their technical process or MPOs might form consortiums to acquire and apply the technical expertise needed to conduct conformity analyses.

Urban travel demand modeling has its origins in the mid-1960s through Federal Highway Administration (FHWA) sponsored travel demand studies focused on several large urban areas, including Chicago, Philadelphia, Pittsburgh, and others. The models produced by these studies and their successors were used to design the Interstate Highway System throughout the US, which was then in the planning stage. The models that evolved during this era were intended to answer the following question B given the anticipated level and pattern of travel for the region B how much additional freeway and major arterial capacity is needed and where should it be located?

In the 1970s and early 1980s, the recommendations of the initial highway studies were widely questioned because of large scale disruption and destruction of urban neighborhoods and landmark historical/cultural institutions. In addition, public transit proponents questioned the efficacy and efficiency of freeway solutions in high travel demand corridors and dense urban areas. As a result of this scrutiny and the accompanying federal highway planning regulations, freeway plans of most large urban regions were scaled back and replaced by expanded proposals for passenger rail and other transit service options. This change in policy emphasis had a significant effect on the specification of most urban travel demand models. Model components related to transit/highway modal split and transit facility assignment were upgraded and improved.

Following the completion of the Interstate Highway System and the first generation of new transit facilities in the 1980s (Washington, DC, San Francisco, Atlanta, Miami, etc.), urban travel demand modeling fell into a period of stagnation. In some urban areas, data sets and models were evaluated and updated regularly and used innovatively, but in other

regions funding and staff levels were insufficient to carry out data collection and model updates. These regions were left with sparse and aging databases and models that had not kept up with advances in the profession.

The passage of the Clean Air Act Amendments of 1990 (CAAA) and the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) drastically changed how Metropolitan Planning Organizations (MPOs) conduct urban transportation planning. Prior to ISTEA, MPOs conducted a continuing, cooperative, and comprehensive (3-Cs) transportation planning process. This process was intended to develop plans that addressed transportation needs and were consistent with overall planned development. ISTEA and CAAA expected MPOs to provide leadership in defining a regional vision through a long-range transportation plan, and produce a Transportation Improvement Program (TIP) that functioned as a strategic management tool to accomplish the objectives of the plan. Major objectives of the transportation plan were to improve the air quality, promote the efficiency and performance of the overall system, and consider a broad range of transportation modes and their inter-connectivity. These regulations were particularly stringent in regions with moderate or worse air pollution problems. Many of the mandated data collection programs and transportation/air quality model upgrades were focused on the estimation, tracking, and prediction of mobile source emissions. These mobile source emissions were part of a larger State Implementation Plan (SIP) that was designed to achieve ambient air quality standards within a specified time limit.

Now, some ten years after the CAAA and ISTEA legislation, many of the traditional uses for travel demand models remain. Highway and public transit systems are still being improved through new facility construction, albeit at a slower rate. Substantial progress has been made towards improving overall air quality, although mandated air pollutant reductions will not be achieved in all regions and the pending introduction of the more stringent 8-hour air quality standard will necessitate redoubled efforts towards mobile source emissions control.

New uses for travel demand simulation and forecasting are also beginning to emerge. The Interstate Highway System and its supporting regional highway network are for the most part more than twenty years old; approaching their design limit both in traffic/volume capacity and pavement life. Because of financial and infrastructure constraints, it will not be possible to accommodate much of the future growth in travel demand through the expansion of the transportation networks. Intelligent Transportation System (ITS) technology can maximize the use of existing capacity, but more aggressive travel demand management policies may also be needed.

Traditionally, spontaneous traveler behavior has utilized all available highway system capacity through alternate routings, peak spreading, trip reduction, and congestion-related traveler responses. But, there are limits to the use of traveler behavior. Congestion dampens economic activity and promotes loss or decentralization of residential, and employment land uses. This is particularly true if congestion levels grow to the point that is difficult or impossible to predict when a given trip will be completed. Work, school, and business travel are predicated on predetermined starting/meeting times. In this

environment, aggressive travel demand management (TDM) and ITS options such as high occupancy vehicle (HOV) lanes, single occupancy vehicle (SOV) restrictions, congestion pricing, and ramp metering may be more politically acceptable. In the planning and evaluation stages of these options, there are significant questions about plan/option effectiveness and related traveler and environmental impact issues. These questions can be answered by appropriately designed forecasting models.

The National Association of Regional Councils (NARC), in conjunction with the Delaware Valley Regional Planning Commission (DVRPC), conducted a national survey of Regional Councils and MPOs to ascertain current modeling practices, the costs of model maintenance, and validation. The survey also collected information about plans for model enhancements and the projected costs associated with these improvements. Modeling practices included three aspects of modeling required by the ISTEA and CAAA legislation: socioeconomic and land use projection, travel demand forecasting, and mobile source emissions calculation. The response to the survey was very good, including over thirty planning organizations. It includes almost all of the large MPOs and a good cross section of medium and smaller regional agencies.

The purpose of this paper is to review the progress of MPOs towards updating and maintaining their models and related travel survey, transportation network, and land use data files, and report on their plans for model enhancement. The survey results, together with emerging planning needs and advances in the information science and modeling methodology, has been used to develop recommendations for inclusion in the next transportation bill now under consideration by the Congress.

Introduction of Land Use, Travel Demand, and Air Quality

Travel demand modeling follows a straightforward behavioral paradigm in which travel demand is derived from the mobility needs of individuals carrying on their daily personal, social, school, and business activities. In the analysis, the amount of travel, type, origin/destination, and specific transportation facilities used is inferred from the spatial distribution of these activities and facilities. This paradigm requires:

- Gathering a large number of data inputs and specifying transportation networks at an appropriately fine level of spatial aggregation called Traffic Analysis Zones (TAZ).
- Preparing traffic zone level forecasts of these such as population, households, auto ownership, and employment; specifying the proposed transportation facilities to be tested; and assuming plausible settings of other model inputs such as auto operating costs, transit fares, personal income and so forth.
- Developing models that accurately represent the travel behavior patterns implied by these forecasts and assumptions.
- Applying these models to the forecasted and assumed data to prepare plausible travel forecasts that are useful in the overall planning process.

The above process involves large data collection and preparation efforts, extensive complicated computer manipulations with semi-custom software, and large amounts of

analyst time to design and calibrate the models and to validate the outputs. Model enhancements tend to be both time- consuming and expensive. For this reason most model enhancement efforts are incremental, making the maximum theoretically correct use of the existing modeling system and its database.

Socioeconomic Data and Land Use

Good results are obtained only if the input data, forecasts, assumptions, and models are adequate. Travel demand analysis requires detailed knowledge of where existing and projected households, businesses, professional and government offices, and other activity generators are located, or are likely to be located. Projection of these variables is typically done in several steps - regional totals of primary variables such as total population and employment are estimated by econometric methods using national, state, and local data and trends. Then, the regional projections are allocated to smaller, intermediate aerial units, such as counties or smaller forecasting districts. These allocations are prepared using a variety of modeling and trending methods and often make heavy use of local knowledge available in county and local planning departments. Formal land use models such as DRAM-EMPAL, and its successors, POLIS, MEPLAN, and others are sometimes used for this intermediate allocation. Finally, the county/forecasting district totals are sub-allocated to traffic zones, and other related variables required by the transportation models are estimated. This is often done by ad hoc techniques that make use of estimates of available land and local knowledge of development plans and proposals, although some variables such as vehicle ownership may be estimated by a formal model.

Travel demand analysis also requires detailed knowledge of the transportation infrastructure available to each traveler. This infrastructure is described through the use of computerized networks made up of nodes and links. These networks accurately describe the service levels provided by highway and public transit facilities through the travel times, distances, capacities, and costs included on the links. Separate networks are almost always developed to represent highway and public transit services, sometimes depicting peak and off-peak congestion levels and service patterns. Provision in the network structure is sometimes made for HOV lanes and rarely for walking and bicycle facilities.

In almost every application, surveys of individual and household behavior are used to provide the empirical travel data needed to develop the model structure and statistical coefficient estimates. The overall performance of the models is then validated by measuring their ability to replicate counted highway link volumes and transit line ridership. These model validation runs typically use Census-derived estimates of the socioeconomic model inputs and transportation networks representative of the facilities opened to traffic during the validation year. These validation exercises are central to the credibility of the models and are performed at regular intervals (ten years or less) to insure that travel volume trends are incorporated into the models and their parameter structures.

The Four Step Travel Simulation Process

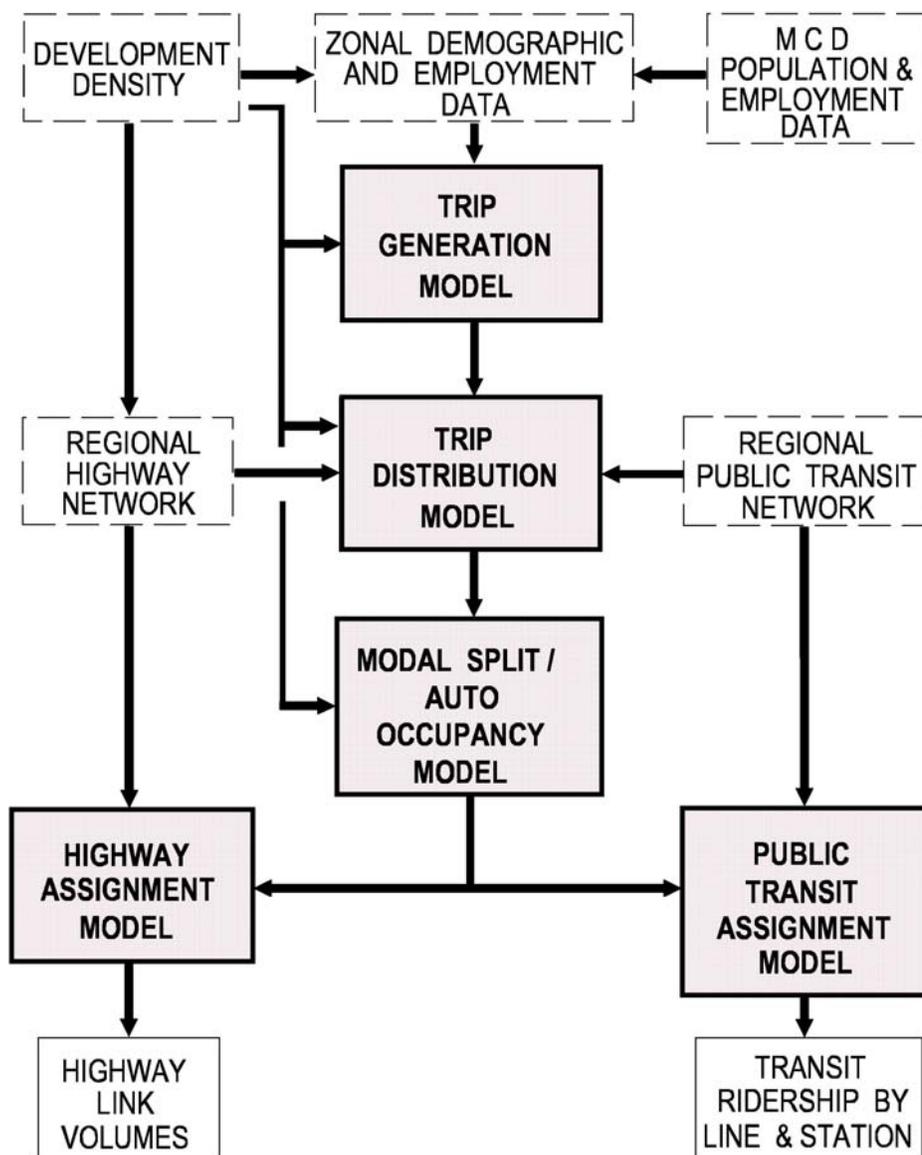
Travel demand models are partitioned into stylized hierarchical elements of the traveler's decision making process commonly called *Asteps* (see Figure 1). Most modeling chains utilize either three or four steps. The difference in the number of steps results from whether highway only or highway and transit travel is being estimated. Four-step processes also include transit travel by generating person travel, which could use either highway or transit modes. An additional model step (Modal Split) is required to separate highway from transit travel. Three-step models generate highway travel directly and do not consider public transit.

In the first step in the four-step process, commonly called *ATrip Generation*, the number of trips likely to be produced by or attracted to the households, businesses, and other activities located in an appropriately small geographical area or TAZ is estimated. Generally, trip productions are made by persons living in households located in the zone, and trips are attracted to persons employed in commercial, institutional, office, and other activities. In theory, the degree of accessibility provided to the TAZ by the transit system should also play a role, but this effect is difficult to identify in survey data. The most common form of trip generation model is cross classification, where average trip rates per person/household or employee are calculated from stratifications of the home interview survey based on household, industrial, or other activity characteristics. These are then applied to the appropriate zonal data to estimate travel. Some trip production models (especially attraction models) employ regression equations based on home interview survey data for the same purpose.

Distribution, step two in the process, matches zonal productions with attractions to produce a spacial pattern of trip making. The typical trip distribution model uses a *Agravity formulation* where the zone I to j volume of travel is directly proportional to the number of trips produced in the origin zone, attracted to the destination zone, and inversely proportional to the cost of travel between the zones. The cost of travel between zones is primarily travel time, either by highway, or in some models, a combination of highway and transit times. The monetary cost of travel (auto operating and transit fare) may play a role in the model. Common functional forms include the gravity model and the logit model which are similar in functional form, and calibrated to survey data.

Auto trips are separated from transit trips and, in some cases, from non-motorized trips in the *AModal Split* or third step of the model chain. Modal split (sometimes called modal choice) models estimate the percentage shares of the travel modes competing for trips in a given zonal interchange as a function of the relative travel time and cost between modes. Other modal characteristics (comfort, convenience, etc.) are implied in the models coefficients which are calibrated from survey data. The modal split step is the most econometrically sophisticated element of the travel modeling chain.

Figure 1
Four-Step Travel Modeling Process



The most commonly used functional form is the nested logit, although some regions use simple logit or other function forms, and a few regions employ the so-called probit form. Both logit and probit can be thought of as a system of simultaneous equations, with an equation included for each mode being considered. The primary difference between logit and probit is in the statistical treatment of the error term included in each equation.

Probit models require explicate a priori knowledge of the error structure in the model calibration, which is difficult to obtain. Nested logit models assume that all equations are independent, but control sub-mode interactions by segregating them into hierarchical levels of the nesting structure. This nesting structure treats interdependent sub-modes as a group for modal split purposes. Because of the inherent tractability of this error structure, nested logit is almost universally used in new modal split models.

The fourth and final step of the travel demand model structure is the association of estimated trips with specific transportation facilities. This *Traffic Assignment* step is accomplished by assigning mode and time-specific trip tables to paths within their respective infrastructure networks. Travel assignment to public transit facilities is done primarily on the basic minimum time paths through published route travel times and service frequencies. Some models recalculate future bus travel times based on projected increases in roadway congestion. Highway assignment models are universally capacity restrained in that the minimum time route selected for assignment through the highway network is cognizant of prevailing congestion levels throughout the network. Traffic congestion is a function of the volume of traffic assigned, and of roadway characteristics in terms of capacity (number of lanes, function class, etc.). Most urban models utilize a true equilibrium assignment process where the solution, in terms of congested speeds and traffic volumes, is determined by mathematical programming techniques. At equilibrium, no trip can be reassigned to a different path in such a way as to reduce the trip travel time. It is assumed that actual driver behavior approximates this equilibrium routing paradigm.

Time Period of the Day and Congested Speed Feed Back Loops

Congestion plays a part in decisions about when to travel, destination choice, travel mode, and travel route. Older travel models estimate average daily travel or, in some cases, peak hour travel, as the peak volumes are a major factor in facility design decisions. In these models, link volumes were the primary model output and link travel time was often used as a calibration parameter to improve the accuracy of the estimated volumes. With the advent of the CAAA legislation, accurate estimated link speeds, as well as volumes, were required to drive the mobile source emissions models. For this reason, the models were disaggregated into separate peak and off-peak processes to more adequately replicate congested travel speeds.

The travel time/capacity function, usually the Bureau of Public Roads (BPR) curve, is formulated in such a way as to prevent any increase to the initial input travel times. Link speeds can be reduced but not increased during the capacity restraint. Therefore, increases in travel speeds resulting from congestion relief will not be modeled, unless the capacity-restraint process is initiated with free flow highway speeds.

There is an obvious inconsistency issue imbedded in the four step process; the trip distribution and modal split portions of the process depend on travel times that are not known definitively until the entire process comes into equilibrium. Congested travel times produce shorter trip lengths from the gravity model, and from the modal split, more transit ridership on rail and other grade separated right-of-way facilities. This, in turn,

reduces highway congestion in the next round of equilibrium assignment, and so forth. Analysts approach this inconsistency in several ways. In older models, the trip distribution and modal split steps are run with preliminary estimates of congested speeds. This reduces, but does not eliminate, the congested time inconsistency.

Another approach is to iterate the travel simulation models by running congested speeds from the highway assignment back through the trip estimation models. Some iterative processes define the feedback loop to include modal split and traffic assignment steps, but as congestion levels also affect trip length and destination choice, it may be more theoretically correct to iterate from trip distribution through traffic assignment.

The iterative model for trip distribution through traffic assignment has a unique equilibrium solution, but most regional models with feedback loops do not iterate the model outputs to convergence. The equilibrium solution requires use of operations research programming algorithms similar to those used to solve the capacity-restrained highway assignment. Currently, there are two methods in use to achieve a near equilibrium solution the Method of Sequential Averages (MSA) and the Evans Algorithm. In both methods, the equilibrium solution is built up from a weighted sum of individual model iterations, but the Evans Algorithm is more sophisticated mathematically and is thought to achieve a near equilibrium solution with less computational effort.

Air Quality Modeling

Mobile source emissions modeling techniques universally involve straightforward summarizations of the highway link volume of the travel simulation model. These summaries are used in combination with emission factors prepared by the EPA's MOBILE series of models, or in California, the EMPFAC/BURDEN models prepared by the California Air Resources Board (CARB). For the most part, these calculations are spreadsheet in nature, where vehicle miles of travel (VMT), cross classified by facility type, type of area, and speed range, are multiplied by the appropriate emissions factor and then summed to regional and sub-regional totals.

The estimation of accurate highway speed distributions is critical to the estimation of mobile source pollutants because the emissions factors vary significantly by speed range. The capacity-restraining functions used in the highway assignment step are generalized and may not be able to produce adequate, detailed speeds for emissions estimation. For this reason, many MPOs employ an emissions postprocessor to re-estimate speeds from the estimated highway volumes and apply these more accurate speeds to the estimation of mobile source emissions. The new MOBILE6 model requires aggregated speed and VMT distributions summarized from the model output. These distributions are then used to calculate an overall emissions factor for use in mobile source pollutant estimation.

There are many other differences between MOBILE5 and MOBILE6 related to vehicle operating regimes, and other assumptions in the design of the post-processor required to summarize the travel demand model outputs. Conversion from MOBILE5 to MOBILE6 requires significant changes to the emissions estimation processes used by MPOs to show

conformity and to make other emissions calculations. MOBILE6 also requires re-estimation of the SIP emissions budgets used in conformity analyses.

Activity Based Modeling

Activity based travel demand modeling reorganizes the trip generation and distribution phases of the four-step process to consider multi-trip tours (trip chaining) rather than individual trips from a given origin to a single destination. A tour is a series of connected trips made by a single member of the household to accomplish a specific primary activity work, shopping, social recreation, etc.

Much of the motivation for activity-based modeling derives from the need to more accurately estimate the number of and origin and destination of non-home based trips. The information about the trip maker income, auto ownership, employment status, and age is CENSUS-based and, therefore, registered by place of residence. Non-home based trips are difficult to forecast with traditional models because little or nothing is known about the person making the trip. Tours also impart a certain logic to the trip making process. In theory, if the trip maker is known to be at the place of work, it is much easier to forecast his lunchtime eat-meal trip than to generate and distribute an equivalent non-home based trip knowing nothing about the trip maker or the purpose of the trip. From a practical point of view, much of the attractiveness of activity based modeling has arisen from the increase in the proportion of and number of non-home based trips in recent home interview surveys. Much of non-home based travel is associated with compound work trips. Modern auto-oriented life styles with both spouses working, promotes multi-purpose work trips such as dropping off the children at day care or school, getting coffee, eating breakfast, or running other errands. From a traditional modeling point of view, this compound work trip would be categorized as a home-based, non-work trip followed by a non-home based trip, blurring the home-work relationship which is relatively easy to forecast.

Computer Software

All urban transportation simulation applications require a suite of computer software programs to support the model application and analyses. A few MPOs still make use of mainframe software programs, such as the Urban Transportation Planning Package (UTPS), for part of their travel modeling applications; but almost all current models require PC or UNIX workstation based model packages. All of the PC/workstation packages replicate, and to some degree augment, the functionality of the UTPS system. TRANPLAN and MinUTP are straightforward adaptations of older mainframe software to the PC environment, while EMME/2, TransCAD, and TP+ provide modeling flexibility beyond the UTPS methodology through simplified user-coded programming languages. TransCAD also incorporates major features of Geographical Information System (GIS) technology directly into the modeling package. TRANPLAN and TP+ provide an interface into the ARCVIEW/ARCINFO GIS package. The graphical capabilities of the GIS environment have simplified the problem of network and database maintenance, and have provided powerful mechanisms for communicating the travel simulation results to transportation professionals and decision makers. However, applying all steps of the modeling process and summarizing the results still require substantial analyst time and

effort.

As part of the federally administered Transportation Model Improvement Program (TMIP), a fundamentally new form of transportation model, TRANSIMS, has been developed. TRANSIMS operates within the UNIX workstation environment, but requires modeling methodologies and computer software that are very different from the UTPS environment.

TRANSIMS

TRANSIMS represents an attempt to completely integrate the travel simulation model into the GIS framework. The most salient aspect of TRANSIMS is the elimination of traffic zones. Travel is simulated for hypothetical, but statistically representative persons traveling from the actual address of origin to the exact destination, over a near literal representation of the transportation infrastructure that includes all local streets, highways, and transit routes. The simulation proceeds, tracking the travel behavior of each individual throughout the day at ten second intervals. As one might expect, TRANSIMS is much more expensive for a region to implement and operate because it requires extreme detail in the land use and transportation network inputs and immense computation and data storage resources. However, the consideration of individual driver behavior allows much more realistic simulation of vehicle operations and delays, and the tracking of individual behavior. This enhanced vehicular detail may improve the ability to evaluate environmental and economic justice issues, model ITS operations, and calculate vehicular emissions.

Traditional trip generation, trip distribution, and modal split models cannot be directly applied in the TRANSIMS framework because they are stochastic in nature, that is, they model the statistical behavior of groups of individuals rather than simulating the behavior of each individual. For this reason, the initial design of TRANSIMS was based on simulations of the travel behavior of synthetic individuals drawn from census demographic profiles, expressing travel characteristics adapted from the trip diaries of persons that responded to the home-interview survey. Initial experiments in Portland, Oregon indicated that this approach was unable to replicate important regional characteristics, such as trip length distributions and modal splits. For this reason, traditional trip distribution and modal split models were used to prepare aggregate travel patterns for control purposes. These data were then disaggregated to individual behavior using monte carlo simulations. As of this writing, the results of the TRANSIMS trials in Portland have not been published and we cannot evaluate the benefits of TRANSIMS vis-a-vis more traditional modeling approaches.

Current MPO Modeling Practices

This section presents an analysis of the current modeling practices that were identified in the survey of the NARC membership taken in the fall of 2002. Overall, thirty-one regional planning organizations responded to the survey. The regional agencies included in the survey are listed in the appendix. A breakdown of the responders by regional

population is given in Table 1.

TABLE 1 - Survey Responses by Region Size

Population	Number of Responses
Less than 200,000	2
200,000 to 500,000	6
500,000 to 1,000,000	6
1,000,000 to 2,000,000	5
2,000,000 to 4,000,000	4
Greater than 4,000,000	8
Total	31

This is a reasonably good sample that has adequate representation from small and mid-size MPOs, and includes almost all of the large metropolitan transportation planning organizations in the US. For purposes of tabulating the results, a regional population of 500,000 was taken as the breakpoint between smaller and large MPOs. Although not the median regional population, this value was selected because there are a large number of MPOs in the US with less than 500,000 in population. Also, for regions larger than 500,000 persons, the complexity of the transportation system and overall planning problem requires a higher level of model sophistication and physical size (networks, zones, etc.). This is also a breakpoint in terms of the staffing level and costs associated with model maintenance and upgrade. In the sample, 13 out of 23 large MPOs and 1 out of 8 smaller MPOs were subject to the final conformity rule modeling requirements.

MPO Forecasting Responsibilities

Table 2 presents the results of the survey with regard to MPO responsibilities for the socioeconomic/land use, transportation, and mobile source emissions forecasts. Also considered, is whether any other agencies were involved in preparing the forecasts. Land use/socioeconomic forecasts were the primary responsibility of 100 percent of the smaller MPOs and 87 percent of the larger organizations. This lower percentage for large MPOs resulted primarily from the Chicago, San Francisco, and Boston regions where regional agencies separate from the MPO are responsible for the socioeconomic forecasts input to the travel models. However, there is a heavy, cooperative, non-MPO presence in socioeconomic forecasting methodologies of most regions (63 percent of smaller and 83 percent of larger MPOs). These are primarily member governments (county, city, and local), although Department of Transportation (DOTs) and other state agencies are also involved. The land use/socioeconomic forecasts are reviewed by these other agencies and adopted through a process of cross-acceptance. Also, localized forecasting tasks, such as traffic allocating control totals to traffic zones may be subcontracted by the MPO to member governments.

All of the smaller and large MPOs are responsible for travel forecasts. There is

significantly less involvement in travel forecasts by other agencies than in land use. Fifty percent of the smaller agencies rely on outside agencies (state DOTs or member governments) to review travel forecasts and in some cases, assist in preparing the inputs and running the models. The percentage is much less B 30 percent B for large MPOs in this case, consisting primarily of reviews by member governments and transit agencies.

TABLE 2 - Land Use, Transportation, and Air Quality Forecasting Responsibilities

Responsibility:	Small MPOS	Large MPOs
MPO prepare Socioeconomic/ Land Use Forecasts	100%	87%
Other agencies or consultants involved in the Socioeconomic/ Land Use Forecasts	63%	83%
MPO prepare Transportation Forecasts	100%	100%
Other agencies or consultants involved in the Transportation Forecasts	50%	30%
MPO prepare Mobile Source Emissions Estimates	25%	70%
Other agencies or consultants involved in the Mobile Source Emissions Estimation	50%	30%

Note: Percentages exclude non-responses.

Smaller MPOs rely heavily on other agencies for emissions estimates. Only about 25 percent of smaller MPOs are primarily responsible for emissions calculation. Fifty percent rely on outside agencies (DOTs and consultants) for this calculation. Also, many smaller agencies are categorized as attainment for air quality purposes and are not required to calculate emissions. Large MPOs are much more likely to be in a non-attainment status. About 70 percent of large MPOs make their own emissions forecasts, and another 30 percent of large MPOs rely on consultants, DOTs, and in California, the CARB.

Land Use Forecasting Procedures

Table 3 summarizes the socioeconomic data/land use forecasting procedures that are currently in place to prepare the inputs to the travel simulation models. None of the smaller MPOs and about one-quarter of the large MPOs employ DRAM EMPAL or one of its decedents in their demographic and employment forecasting process. There are

widely varying degrees of satisfaction with DRAM EMPAL. A few MPOs are planning to upgrade the model or replace it with another approach. Some 13 percent of smaller and 27 percent of larger MPOs have devised their own socioeconomic forecasting processes that are defined and well documented enough to be considered models. The remainder of MPOs use cooperative processes with their member governments that involve regional total estimation and progressive sub-allocation to smaller and smaller areal units using local knowledge (zoning regulations, development proposals, etc.). Thirteen percent of smaller MPOs and 35 percent of larger MPOs incorporate a feedback loop from planned major transportation facilities into the land use forecasting process.

TABLE 3 - Socioeconomic/Land Use Forecasting Procedures

Forecasting Procedure:	Smaller MPOs	Large MPOs
MPO utilizes a standardized Land Use model	0%	23%
MPO uses a locally developed formalized Land Use model	13%	27%
Land use procedures include a Transportation Feedback Loop	13%	35%

Note: Percentages exclude non-responses.

Travel Demand Modeling Procedures

Table 4 summarizes the travel simulation/forecasting models currently in use. Smaller MPOs are about equally split between the Three-Step and Four-Step processes. Smaller regions usually lack an extensive public transit system. This greatly reduces the need for the modal split and transit assignment steps of the four-step process. All large MPOs have significant public transit systems and use the Four-Step, or in one case, an activity based model that includes transit. Not all MPOs with a Four-Step process can adequately model public transit. Only 38 percent of the smaller and about 87 percent of the larger MPOs, claim to model public transit. A distinct minority B 25 percent of the smaller and 32 percent of the larger MPOs B also model non-motorized travel (walking, bicycling) as an alternative to auto and transit travel. An even smaller minority (13 percent) of smaller MPOs , and 32 percent of larger MPOs, explicitly model commercial/truck trips.

Some 25 percent of smaller MPOs and 64 percent of the larger MPOs have the congested travel time feedback loop required by the air quality conformity rule. However, many agencies omitting the loop are not required to incorporate this feature into their model because they don=t have the population size or air pollution severity stipulated in the rule. All of the smaller and 95 percent of larger MPOs that responded, reported that their travel forecasts had credibility with decision makers and the general public.

TABLE 4 - Travel Demand Forecasting Procedures

Type of Model:	Smaller MPOs	Large MPOs
Three-Step Model	50%	0%
Four-Step Model	50%	96%
Activity-Based Model	0%	4%
Model includes Public Transit	38%	87%
Model includes non-motorized travel	25%	32%
Model explicitly estimates truck/commercial vehicle trips	13%	32%
Model has a congested time feedback loop trip distribution/modal split	25%	64%
Forecasts have credibility	100%	95%

Note: Percentages exclude non-responses.

Mobile Source Emissions Estimation

The methodologies used by MPOs to convert their travel forecasts into mobile source emissions are summarized in Table 5. Some 37 percent of smaller and 39 percent of larger MPOs still use MOBILE5 to estimate vehicular emissions factors. Nationally, we are now in the process of converting the conformity process from MOBILE5 to the USEPA's new MOBILE6 model. Over the next two years, non-attainment regions are required to switch from MOBILE5 to MOBILE6 in their conformity demonstrations. The totals for smaller MPOs do not add to 100 percent because 63 percent are in air quality attainment and are not required to estimate emissions. The summed percentage for large MPOs using MOBILE5 or MOBILE6 (61 percent) is less than using a postprocessor (81 percent), because three MPOs in the sample use the California emissions model (Burden). Also, 19 percent of the large MPOs do not use a postprocessor because one is in attainment and does not calculate emissions and four MPOs estimate emissions directly from modeled speeds.

TABLE 5 - Mobile Source Emissions Estimation Procedures

Type of Model:	Smaller MPOs	Large MPOs
MOBILE5 process	37%	39%
MOBILE6 process	0%	22%
Postprocessor-based travel speeds from assigned volumes	37%	81%

Note: Percentages exclude non-responses.

Travel Demand Model Validations

The CAAA and ISTEA legislation, conformity guidance, and good modeling practice all require that travel simulation model output be validated against current highway and transit count data at regular intervals. Census, home interview, and other survey data are also included in the validation process to validate and re-calibrate model parameters as needed. Most MPOs undertake a major validation every ten years based on decennial Census, home interview and special survey data, and at least one minor mid-decade validation, during the interval between the Census, based primarily on traffic and transit counts. Production schedules for Census Journey-to-Work data, and funding, and manpower availability for surveys can shift the model validation year away from the Census cycle. The ten-year validation requirement in the final conformity rule invariably requires validations more often than ten years. This is because timing shifts in Census and survey data availability delays the validation beyond the ten-year maximum. As a result, expensive interim year forecasts are prepared solely for model validation purposes. The conformity process would be more efficient, and results better, if the conformity rule requirements were benchmarked to coincide with the availability of the Census data.

Table 6 presents the survey results on questions regarding model validation. One-half of the smaller MPOs validated their models at five-year or shorter time intervals and the other 50 percent, every 10 years. Large MPOs validated their models more often, 70 percent every 7 years or sooner, and the other 22 percent within 10-year intervals. About 86 percent of both small and large MPOs use the Census Journey-to-Work data in their model validations, and 63 and 70 percent use home interview or other special survey data. All MPOs base their model validations on transit and/or highway count data. Some 42 percent of smaller and 52 percent of larger MPOs use consultants to conduct model validations.

TABLE 6 - Travel Demand Model Validation

	Smaller MPOs	Large MPOs
How often do you validate your Travel Demand Model?		
Every 2 to 5 years	50%	61%
Every 5 to 7 years	0%	9%
Every 10 years	50%	22%
Use Census Journey- to-Work data in your model validation	83%	86%
Collect home interview or other survey data for your model validation	63%	70%
Validation based on Transit and Highway count data	100%	100%
Model validation performed by consultants	42%	52%

Note: Percentages exclude non-responses.

Uses for Travel Demand Model Outputs

The uses for model output identified in the survey are displayed in Table 7. Three-quarters of smaller MPOs and all larger regional planning commissions use their model's output for facility design and corridor studies. This also includes Major Investment Studies (MIS) and Environmental Impact Studies (EIS). More than 80 percent of MPOs use their models to evaluate the long-range transportation plans. These are the original uses for travel demand models. TIP/Plan conformity is another use for the models in non-attainment air quality regions. Some 13 percent of smaller MPOs and 62 percent of larger MPOs are required to show conformity. Other significant uses mentioned in the survey responses include congestion management, land use scenario testing, environmental justice, and ITS planning.

TABLE 7 - Uses for Travel Forecasting Model Output

Output Use	Smaller MPOs	Large MPOs
Facility Design, Major Investment/ Environmental Impact Studies	75%	100%
TIP/Plan conformity	13%	62%
Long-range plan evaluation	87%	82%
Congestion/Travel Demand Management	38%	55%
Evaluate Land Use Scenarios	13%	18%
Environmental Justice	13%	36%
ITS Planning	38%	18%

Note: Percentages exclude non-responses.

Travel Forecasting Requirements for Conformity Analyses

The modeling guidelines for conformity analyses are generally oriented towards preparing accurate estimates of mobile source emissions. The final joint USEPA/USDOT rule for conformity analysis stipulates six requirements for serious and worse Ozone non-attainment and Carbon Monoxide (CO) non-attainment areas with populations above 200,000:

- Network-based models must be validated against observed counts (peak and off-peak, if possible) for a base year that is not more than ten years prior to the date of conformity determination.
- Model forecasts must be analyzed for reasonableness and compared to historical trends and other factors, and the results documented.
- Land use, population, employment, and other network model assumptions must be documented and based on the best available information. Scenarios of land development and use must be consistent with future transportation alternatives for which emissions are being estimated. The distribution of employment and residents for different transportation options must be reasonable.
- A capacity-restrained traffic assignment methodology must be used, and emissions estimates must be based on a methodology that differentiates between peak and off-peak speeds.
- Zone-to-zone travel times used to distribute trips must be in reasonable agreement with the travel times that are used in the final assigned traffic volumes. Where transit is anticipated to be a significant factor in satisfying travel demand, these final travel times should also be used to estimate modal splits.

- Finally, network-based models must be reasonably sensitive to changes in the time(s), cost(s), and other factors affecting travel choices.

In the mid-to-late 1990s most MPOs undertook major model enhancement programs to satisfy these requirements, although those regions with enforceable requirements (severe or greater non-attainment and populations over 200,000) undertook the greatest effort. The quality of the models used to show conformity have become a major focus of legal challenges to regional plans and programs by environmental groups. There is considerable variation from region to region in how models were upgraded and how they are utilized in the overall planning process. Much of the variation reflects localized issues and the local planning culture. In the sample, 13 out of 23 large MPOs and one out of 8 smaller MPOs fell within the final conformity rule modeling requirements.

Table 8 shows the degree of MPO compliance with conformity rule mandated model characteristics for two categories of MPOs: those covered by the rule and those exempt from the rule. As discussed in the section above, validation every ten years might not be frequent enough to insure that all conformity analyses are based on current models. Although the results appear to be the same for covered and exempt MPOs, as discussed previously, all MPOs covered by the rule validate their models more frequently than ten years in order to meet the requirement. All MPOs have a cooperative land use/socioeconomic data forecasting process with member governments and, in some cases, even utility company reviews and cross acceptance. Three of the large MPOs rely on sister regional agencies for forecasts of the socioeconomic inputs to the models. All regional models include a capacity-restrained highway assignment and have some sensitivity to time and cost factors.

The model requirements that are unique to the conformity rule clearly show the effect of the requirements on modeling practices. Covered agencies are more than twice as likely to have a congested time feedback loop within their model structure as are exempt organizations (85 percent versus 33 percent for large and 100 percent versus 14 percent for small). Similar

differences (92 percent versus 50 percent) exist among large MPOs for peak and off-peak speeds and volumes. However, smaller exempt MPOs are more likely (29 percent versus 0 percent) to separate peak and off-peak model runs than covered agencies.

TABLE 8 - Compliance with Conformity Rule Mandated Modeling Procedures

MPOs Covered by Conformity Rule:	Smaller MPOs**	Large MPOs
Validate Every 10 Years*	100%	100%
Land use/socioeconomic requirements	100%	77%***
Capacity-restrained assignment	100%	100%
Peak and off-peak speeds and volumes	0%	92%
Congested travel time feedback loop	100%	85%
Models sensitive to time and cost factors	100%	100%
Expect change in attainment status as a result of the 8-hour standard	0%	50%
MPOs Exempt from Conformity Rule:	Smaller MPOs	Large MPOs
Validate Every 10 Years	100%	100%
Land use/socioeconomic requirements	100%	100%
Capacity-restrained assignment	100%	100%
Peak and off-peak speeds and volumes	29%	50%
Congested travel time feedback loop	14%	33%
Models sensitive to time and cost factors	100%	100%
Expect change in attainment status as a result of the 8-hour standard	57%	75%

Notes: Percentages exclude non-responses.

* All MPOs covered by the conformity rule validate every 7 years or less.

** Only one MPO in this category.

*** Three large MPOs have land use/socioeconomic forecasts made by a sister agency.

Some 50 percent of large covered MPOs expect their attainment status to change as a result of the pending 8-hour air quality standard. All smaller covered MPOs expect their attainment classification to remain the same under the 8-hour standard. For exempt large

agencies, the percentage expected to be reclassified as non-attainment increases to 75 percent. The corresponding percentage for exempt smaller MPOs is 57 percent, reflecting the fact that air pollution problems are often not as severe in smaller regions.

Planned Improvements in Travel Forecasting Models

One of the questions in the transportation modeling section of the survey asked if the MPO planners were happy with their transportation model. The response to the question indicates that 63 percent of the smaller and 87 percent of large MPO professionals were happy with their models. Clearly, there are no current plans for massive alterations or extensions to the models. Although planners are not as happy with land use as with the transportation model, most MPOs want to continue to maintain and validate their models and to correct selected deficiencies. The most frequent planned change is to update the model software. Enhancements are also planned to correct deficiencies, keep models consistent with current practice, and include Conformity Rule mandates that have not yet been implemented.

Planned Land Use Model Enhancements

Table 9 lists the planned model enhancements that were identified from the survey. Only about 13 percent of the smaller MPOs and 9 percent of the larger MPOs are contemplating implementing a new standardized land use model. Standardized model refers to a clearly defined, published model such as DRAM EMPAL or METROPOLIS. One-third of the larger MPOs are planning to upgrade their existing land use model or forecasting procedures. About one-quarter of the smaller and large MPOs are planning to implement a feedback loop between published model such as DRAM EMPAL or METROPOLIS. One-third of the larger MPOs are planning to upgrade their existing land use model or forecasting procedures. About one-quarter of the smaller and large MPOs are planning to implement a feedback loop between transportation and land use and about 27 percent of the large MPOs are planning to enhance their land use processes through GIS techniques. All of the smaller MPOs intend to enhance their land use procedures through consultants, but the larger MPOs have a tendency to do this work in-house. About 36 percent of large MPOs intend to involve consultants in their land use model upgrade.

TABLE 9 - Planned Land Use Model Improvements

	Smaller MPOs	Large MPOs
Enhancement:		
Implement new Standard Land Use Model	13%	9%
Upgrade existing Land Use Model/process	0%	36%
Implement transportation/land use feedback loop	25%	23%
Enhance GIS aspects of Land Use forecasting	0%	27%

Note: Percentages exclude non-responses.

Planned Transportation Model Enhancements

On the transportation side (see Table 10), 63 percent of smaller MPOs and 59 percent of large MPOs intend to upgrade their computer software. Much of this upgrade involves switching to the TransCAD package. A lot of the appeal of TransCAD emanates from its integrated GIS capabilities. Overall, 50 percent of smaller and 45 percent of large MPOs intend to upgrade their transportation GIS capabilities.

Twenty-seven percent of large MPOs plan to upgrade the trip generation/distribution phases of their models to activity based designs. A few MPOs plan to implement separate peak and off-peak models and implement congested travel time feedback loops in order to achieve compliance with the Conformity Rule. Other planned model upgrades include improved transit and commercial/truck models, and implementing non-motorized travel models. Transit model upgrades are intended to upgrade from Three-Step to Four-Step processes or to improve transit forecasts from an existing Four-Step model. Some 72 percent of the smaller MPOs and 89 percent of the large agencies plan to involve consultants in their model upgrade projects.

Two large MPOs (9 percent) intend to implement TRANSIMS. Both of these have already been involved in the TRANSIMS model demonstration program.

TABLE 10 - Planned Transportation Models Improvements

Enhancement:	Smaller MPOs	Large MPOs
Upgrade/replace software	63%	59%
Implement Activity Based model	0%	27%
Implement Separate Peak and Off-peak model	13%	5%
Implement congested times feedback loop	0%	9%
Enhanced GIS/Transportation interface	50%	45%
Non-motorized travel	0%	14%
Transit modeling	13%	18%
Truck/commercial modeling	13%	18%
TRANSIMS	0%	9%
Use consultants in model upgrade activities	72%	89%

Note: Percentages exclude non-responses.

Planned Expenditures for Model Maintenance and Enhancement

The survey also asked the respondent about planned expenditures for model validations with 2000 Census and Survey data and planned model and software upgrades. These upgrades for the most part reflect incremental improvements to the existing models. The resulting annual average planned expenditures are given in Table 11. There is a very large difference between smaller and large MPO=s planned expenditures. This, in part, reflects model complexity and funding availability. On average, smaller MPOs plan to spend \$40,000 per year on land use models and large MPOs plan to spend \$180,000. Much larger expenditures are planned for transportation models B \$130,000 per year for smaller and \$500,000 for larger MPOs. This cost difference, in part reflects expensive home interview survey and model enhancement projects spread over several years. MPOs plan to spend \$50,000 and \$100,000 per year for emissions model upgrades. This cost reflects the transition from MOBILE5 to MOBILE6 and related conformity budget expenses.

TABLE 11 - Planned Average Annual Model Maintenance and Upgrade Expenditures

Category	Smaller MPOs	Large MPOs
Socioeconomic/land use models	\$40,000	\$180,000
Travel demand models	\$130,000	\$500,000
Mobile source emissions models	\$50,000	\$100,000
Total	\$220,000	\$780,000

One should remember, when interpreting these cost figures, that these are rough estimates that can vary significantly from one MPO to another, depending on the local situation and the character of upgrade that is planned. In aggregate, these planned expenses are comparable to historical spending rates over the last 10 years. These expenditures are necessary to sustain MPO modeling capabilities at the current level. There is variation between large and very large MPOs. The average transportation model expenditures for MPOs with regional populations over 4,000,000 is \$780,000, compared to the \$500,000 average for all large MPOs.

D. NARC=s Role in Promoting MPO Modeling

The survey questionnaire also asked if NARC should take a proactive role in providing modeling guidance, updating the best practices manual,¹ and lobbying for MPO interests in the transportation legislation now before the Congress. Overall, Table 12 shows that there is overwhelming support for continuing NARC involvement in all three areas. Almost all of the smaller MPOs indicated that NARC should provide modeling guidance and update the best practices manual. About three-quarters of the large MPOs felt the same way. There was concern that any guidance should be advisory and that local autonomy in modeling practices should be preserved. Several MPOs expressed the hope that NARC and the Association of Metropolitan Planning Organizations (AMPO) could work together and coordinate their efforts in this area.

Some 80 percent of both small and large MPOs felt that NARC should lobby for MPO modeling interests in the upcoming federal legislation, particularly to insure that sufficient funds are made available for planned model validations and enhancements.

¹Manual of Regional Transportation Modeling Practice for Air Quality Analysis, National Association of Regional Councils, Washington, D.C., 1993.

TABLE 12 - NARC=s Role in Promoting Modeling

	Smaller MPOs	Large MPOs
NARC should provide modeling guidance	86%	76%
NARC should update the Best Practices Manual	100%	74%
NARC should lobby for MPO modeling interests	80%	82%

Legislative Program for MPO Modeling Capabilities

Most urban regions of the United States face relentless continuing growth in highway travel volumes as a result of population and employment growth. Decentralization of land use patterns into auto-oriented suburban and rural areas also plays a role, as do demographic shifts, increases in auto ownership, and other causes.

The urban travel demand forecasting models are, and will continue to be, an integral part of the planning establishment in all urban regions in the US. As the urban fabric of the US matures into an auto-oriented development pattern, transportation infrastructure capacity expansion is increasingly difficult from the financial, legal, and environmental impact standpoints. In this setting, the models become even more important in optimizing and legitimizing planning efforts and resolving related disputes. Uses of the models can be categorized into five interrelated areas, briefly discussed in the following sections.

New Transportation Facility Construction and the Expansion of Existing Facilities

Continued growth in highway congestion has precipitated intense demand for additional system capacity through the construction of new highway and transit facilities, and the expansion of existing facilities. Facility expansions are often coordinated with the design life-related reconstruction of existing facilities. This traditional use of travel forecasting models, and the demand for corridor, major investment, and environmental impact studies is intense. The models are also used for the traditional functions of evaluating the transportation element of the long-range plan.

Land Use Planning and Growth Management

Long-range land use planning usually involves evaluation of land use scenarios. An important factor in the evaluation of these scenarios is the impact on the transportation infrastructure through the evaluation of congestion and environmental impacts. Smart growth planning attempts to make maximum use of the existing highway system and encourage development patterns conducive to public transportation. The models provide an indication of the probable success of smart growth.

Travel Demand Management

Congestion management is in part based on projected levels of congestion. Also, the current travel forecasts provide estimates of traffic volumes and congestion levels on roadway links not covered by traffic counts and travel time surveys. Planning for public transit and HOV facilities is heavily dependant on the use of the models to evaluate alternatives and design new facilities. Non-motorized travel is not traditionally considered by the models, but will play an increasing role in transportation planning.

Economic and Environmental Justice

Environmental justice issues related to planned facility improvements have emerged. These include the environmental and neighborhood impacts of new highway and transit, and the distribution of associated benefits. Economic justice will also be a concern if more widespread designation of HOV lanes and other single occupancy vehicle restrictions, congestion pricing, and aggressive traffic control measures are used to control vehicular congestion. Planning for implementation of these measures is likely to be difficult. The models have a role in evaluating the efficacy of transportation proposals and quantifying the environmental and economic impacts.

Environmental Concerns and Air Quality Planning

This is a very important continuing use of travel demand models, particularly in regions that have to continue to demonstrate conformity of their capital program with air quality standards. This may result from not having achieved attainment with the 1-hour standard or still being in air quality maintenance mode. Continuing growth in highway travel may threaten air quality even in regions that have reached attainment. The more stringent 8-hour standard will result in reclassification of most if not all medium and large MPOs into non-attainment.

Larger MPOs already have network-based travel simulation models and have staffs capable of applying them. MPOs, some originally classified as moderate or better under the 1-hour standard, may have to upgrade and validate their transportation models and acquire mobile source emissions estimation capabilities as a result of the 8-hour standard. These upgrades, for the most part, can be undertaken within ongoing model maintenance and enhancement activities.

The more stringent new 8-hour air quality standards are also likely to result in regulation of mobile source emissions for hundreds of new counties in the United States. Most of these newly regulated counties will probably be located east of the Mississippi River. Many of them are served by small urban MPOs or rural planning agencies that do not have the transportation and mobile source emissions modeling expertise or adequate staffing levels to independently conduct in-house conformity demonstrations.

Provisions in the new law must be made to provide the required support to these smaller organizations. In general, three paradigm could be followed to provide conformity demonstration support for smaller MPOs.

1. States could provide smaller MPOs with conformity demonstrations support as an

- adjunct to the SIP development process.
2. Smaller MPO=s could band together into consortiums and hire consultants and prepare conformity analyses as a group. Or,
 3. Smaller MPO=s could go it alone and acquire their own conformity demonstration resources through staff acquisitions or consultant contracts.

In most cases, the third option is likely to be the least efficient mode of operation and will be unacceptable. There are significant economies of scale in combining the technical work associated with conformity analyses for small urban and rural planning organizations. It is natural to provide support for newly re-designated smaller MPOs from the state because many of the emissions calculations and processes required to prepare the SIP are directly applicable for conformity demonstrations. It may be possible to provide for the conformity demonstration needs of all of the smaller MPOs within the statewide SIP consultant contract. Existing staff in these organizations who prepare the TIP and long range plan may be adequate to prepare conformity demonstrations using methods provided by State transportation and environmental protection agencies through their consultants.

However, consortiums of smaller MPOs may be attractive and provide acceptable economies of scale in some situations. The choice between the three paradigms depends on the size and spacial distribution of non-attainment MPOs and the planning culture that exists at the local, regional, and state levels.

Specific Legislative Recommendations

It is very clear that the travel demand models and related land use and emissions estimation procedures will continue to be the most important elements in regional transportation and environmental planning activities. The new transportation bill should make explicit provisions for the validation and maintenance of regional models and for selective upgrades. These enhancements are needed to remain consistent with acceptable modeling practice and to address emerging transportation planning issues. The bill must make adequate funding levels available to MPOs and states for these activities.

Suggested guidelines for this legislation follow:

1. *Adequate funding for routine model validation, maintenance, and enhancement should be provided.* Section IV-C provides an estimate of planned spending by MPOs on their models. This planned spending, for the most part, reflects required model validations and incremental improvements to the models and related software. Lawsuits related to proposed transportation projects are very common. Issues related to the adequacy of the travel forecasting models used in planning stages are always central to the legal arguments and often pivotal in the decision.

2. *MPOs should be given flexibility to tailor their modeling processes to local planning issues and requirements.* The flexibility is particularly important for land use modeling. However, transportation modeling requirements also reflect the local planning culture in terms of transportation issues, data availability, and the current specification of the models.

3. *Detailed model specification issues should not be addressed in the legislation.*

Rather, funds should be made available to update the 1993 NARC Best Practices Manual. There is a need for an updated review of best practices. The travel modeling community is served by an active academic and professional community that can assist in this task.

4. *If new transportation planning initiatives not adequately addressed by regional models are included in the bill, funding for the required model upgrades should be provided.* Modeling of congestion pricing and other aggressive demand management policies may require model upgrades. The data and computation requirements of TRANSIMS are very large and extensive. As of this writing, the results of the model trials in Portland, Oregon have not been published. Therefore, NARC can't take a position on the implementation of this new model at this time. However, implementing TRANSIMS will be a very large and expensive effort for MPOs. It requires a near complete replacement of the existing regional models and their associated databases. Specific funding must be provided in the bill for TRANSIMS implementation, if the decision is made to go ahead with the model.

5. *Model requirements, such as validations, should be coordinated with the availability of Census and other survey data.* This will improve the efficiency of the conformity process and improve the quality of the results by eliminating the need for interim year validation forecasts.

6. *Specific provisions should be made in the bill to provide technical resources for MPOs who are placed in a non-attainment status as a result of the 8-hour air quality standards.* For smaller MPOs, this conformity demonstration support, in many cases, may be provided by state environmental protection and transportation departments as an adjunct to the SIP development process. Special situations may also exist where individual large MPOs might need to upgrade their technical process or MPOs might form consortiums to acquire and apply the technical expertise needed to conduct conformity analyses.

Appendix

List of Participating Metropolitan Planning Organizations

Akron Metropolitan Area Transportation Study (AMATS)
Anchorage Metropolitan Area Transportation Study (AMATS)
Atlanta Regional Commission
Bi-State Regional Commission Rock Island, IL
Boston Metropolitan Planning Organization
Champaign County Regional Planning Commission (IL)
Chicago Area Transportation Study
Delaware Valley Regional Planning Commission (DVRPC)
Des Moines Area MPO (DMAMPO)
Hampton Roads Planning District Commission
Indianapolis MPO
Kern Council of Governments
KIPDA Louisville, KY
Lafayette Consolidated Government
Lehigh Valley Planning Commission
Maricopa Association of Governments
Metropolitan Area Planning Agency (MAPA)
Metropolitan Transportation Commission
Mid-America Regional Council (Kansas City, MO)
New Jersey Transportation Planning Organization (NJTPA)
New York Metropolitan Transportation Council (NYMTC)
North Central Texas Council of Governments
Portland Metro
Rhode Island Statewide Planning Program
San Diego Council of Governments

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111 S. Independence Mall East, Philadelphia, PA 19106
602 East First Street, Des Moines, IA 50309-1881
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200 E. Washington Street, Suite 1841, Indianapolis, IN 46204
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11520 Commonwealth Drive, Louisville, KY 40299
PO Box 4017-C, Lafayette, LA 70502
961 Marcon Blvd., Suite 310, Allentown, PA 18109
302 North 1st Avenue, Suite 300, Phoenix, AZ 86003
2222 Cuming Street, Omaha, NE 68102-4328
101 Eighth Street, Oakland, CA 94607
600 Broadway, Ste. 300, Kansas City, MO 64105
One Newark Center, Newark, NJ 07102
45-46 21st Street, Long Island City, NY 11101
616 Six Flags Drive, Arlington, Texas 76005
600 Northeast Grand Avenue, Portland, OR 97232-2736
One Capital Hill, Providence, RI 02908
401 B Street, Suite 800, San Diego, CA 92101

South Jersey Transportation Planning Organization (SJTPO)

Southeast Michigan Council of Governments (SEMCOG)

Southeast Texas RPC

Southern California Association of Governments

Southwest Washington Regional Transportation Council (Vancouver)

West Florida Regional Planning Council

1173 Lands Ave., Vineland, NJ 08360

535 Griswold Street, Suite 300, Detroit, MI 48226

P.O. Drawer 1387, Nederland, TX 77627

818 West 7th Street, 12thFloor, Los Angeles, CA 90017-3435

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R Transport Model: Developing Open-Source Urban Transportation Models Using the R Programming Language

Brian Gregor, *Oregon Department of Transportation*

Abstract. The Oregon Department of Transportation (ODOT) has developed a set of transportation modeling programs for small urban areas in the state using the R programming language. All parts of the modeling process, except for traffic assignment are carried out by these programs. Assignment is handled by emme/2 with automated process control by R. ODOT is working with MPO modelers to extend the software to develop a common programming framework for implementing travel demand models in the state in R.

This work was begun for several reasons. First, various parts of travel demand models were being implemented in a variety of software packages and programming languages. This increased the work of debugging, maintaining and updating models. In addition, the programs could not easily be altered for reuse in other areas. Second, Oregon modelers had estimated joint models for small urban areas and for MPO areas. A logical next step another set was to develop a common programming framework for implementing the models. This has the benefits of making programs more transferrable, increases the number of modelers who understand the programs, and allows modelers to spend more time on improving modeling capabilities and less on rewriting code. Third, modelers were running into propriety software limitations. Models were getting larger and more complex. Increasingly custom programming in various systems languages was becoming necessary because the scripting or macro capabilities of proprietary software were not adequate. In addition, modeling applications were running into size limitations imposed by software packages. Oregon modelers could no longer rely on proprietary software to keep up with our needs.

The R programming language was chosen for developing these models because:

- It has strong data handling capabilities,
- It has many operators for calculating with vectors and matrices,
- It includes many tools for data analysis, most notably an extensive set of statistical analysis tools,
- It has powerful graphics capabilities,
- It is a complete, object-oriented programming language with all of the control functions needed to implement models, and
- It is open-source and cross-platform.

R can be thought of a modeling environment because the modeler can use it in everyday work to analyze data, estimate models, develop data visualizations, and develop and run models. This means that modelers can program models in the environment they use in their daily work. Furthermore, because R is open source and cross-platform, the language can be extended as needed, and it can be implemented anywhere without purchasing a license for a proprietary product. This paper will describe how the R programming language can be used for transportation modeling and how it has been used in Oregon to implement small urban area transportation models.

Analysis of Link Capacity Estimation Methods for Urban Transportation Planning Models

Yogesh Dheenadayalu, *Metasolv Software Inc.*; Brian Wolshon, Ph.D. and Chester Wilmot, Ph.D., *Louisiana State University*

Abstract. A common travel analysis technique is to ascribe capacities to links in a planning network based on functional classification or facility type. Under which a four-lane divided arterial, for example, would be assigned the same capacity everywhere, irrespective of the surrounding land use, the presence of traffic signals, and whether turning lanes are provided or not. While this practice has been used for many years and is typically adequate for the analysis of large road networks, there are penalties (in terms of lost accuracy) that accompany its use. The objective of this research was to evaluate different techniques to determine what information was necessary to reasonably estimate link capacity while decreasing the time, effort, and cost of data collection. It was found that assigning capacities on a link-specific basis produced significant differences when compared to the practice of assigning average capacities, suggesting that travel demand modeling could be improved by using link-by-link estimates of capacity. The results of this study also supported the concept that improvements gained by using all HCM adjustment factors were marginal compared to the improvement achieved by including only the g/C ratio and number of lanes; suggesting further that ignoring other factors like lane widths, heavy vehicles, turning movements, etc. will still result in reasonably accurate estimates of volume, travel time and travel speed.

Method to identify optimal land use and transport policy packages

Guenter Emberger, Simon Shepherd, and Agachai Sumalee, *ITS Leeds*

Abstract. The main purpose of the introduced methodology is to help city authorities to identify city specific optimal Land Use and Transport (LUTR) strategies to meet their future needs and targets.

The presented methodology is based on an ongoing UK research project, where it is applied and tested at 6 cities. The project is the latest out of a series of research projects carried out on UK and European level.

The main idea is to connect traditional steps, which have to be carried out to identify optimal LUTR- strategies and to automate their interaction, and thus enables to find optimal city specific solutions. The following picture shows how the different parts are woven together and depicts at the same time the necessities to set up the process:

To be able to carry out the optimization process a series of initial steps have to be done:

Set up process in collaboration with the cities:

1. definition of city specific scenarios concerning growth rates, economic development etc
2. set up of a city specific LUTR-model This model includes all city specific information, zoning system, inhabitants, workplaces, housing etc.
3. definition of a set of policy instruments and their city specific ranges.
4. agreement on a city a city specific appraisal of impacts.

Optimization process: If the set up is finished the optimization process can be started, which is expressed by the green loop of arrows. The loop policy packages – LUTR-model – Assessment of Impacts – New policy package is carried out till no “better” policy package can be found. These iterations are the optimization process. Depending on the complexity of the method to assess the impacts a different number of iterations is needed to stop the process. The number of policy instruments and their spatial and temporal disaggregation also determine the number of iterations.

As policy instruments we consider instruments for Pedestrians (Pedestrianisation), Public Transport (New PT-Infrastructure, Fares, Frequency), Private Car (New Roads, Road Pricing, Parking charges, Road capacity increase/decrease, Fuel tax, Parking supply), and Land use measures (Controls on development, Land use charges). We use 3 different LUTR models (START/DELTA, SPM, TPM) which operate on different detail levels. The LUTR models provide information about land use and transport system developments for a 30 year period. These information will be used to appraise the impacts of the applied instruments against city specific objectives using a Cost benefit analyses (CBA) – Multi Criteria Analyses (MCA) based approach.

Within this paper we will introduce the findings derived in the project so far. We will report the progress in the set-up process of the tools and their city specific application. Special focus will be put on issues concerning the appraisal process, explain which indicators are taken into account, how we solve the weighting problem in CBAs/MCAs, etc. Since we work close together with the city councils of the 6 case study cities practical relevant findings are ensured.

The UK 1998 Transport White Paper advocated the use of integrated transport strategies, including transport infrastructure, management and pricing measures as well as land use interventions, as ways of achieving the government's objectives in urban areas (DETR, 1998). That approach was subsequently reinforced in the government's guidance on the Local Transport Plans (and their equivalents) which all local authorities outside London submitted in 2000 (DETR, 1999a) and in the revised version of Planning Policy Guidance 13: Transport (DETR, 2001).

The concept of integrated transport strategies is not new; many local authorities were developing them in the early 1990s (May, 1991, May and Roberts, 1995) and they were a key element in the first ECMT report on transport and sustainability (ECMT, 1995). However, few Local Transport Plans (LTPs) can be considered as truly "integrated" as yet in their approach; they are limited in particular by the resources available, the unacceptability of demand management measures, the need to negotiate with operators on public transport service levels and fares, the lack of understanding of interactions between transport and land use, and the timescale for implementing innovative solutions.

There thus remain significant challenges both in the short term design of strategies and in the longer term fundamental understanding of their performance. Among the key issues are the need to understand how best to combine the wide range of different policy instruments; how to identify the optimal combinations of these, given that most can vary substantially in the ways in which they are implemented; how to reflect constraints of finance, institutional responsibilities, technology and public acceptability in their design; how to develop implementation sequences which enhance their performance; and how far it is possible to transfer strategy specifications from one city to another.

These issues have been addressed in a series of our previous work where we have made significant advances in understanding the design of optimal transport strategies. In former research we proved the usefulness of optimisation methods to identify optimal transport strategies (Fowkes et. al., 1998). In follow up research we studied the performance of transport policy packages in regard to the level of implementation (May et. al., 1997), their financial feasibility (May et. al., 1998) and their transferability (May 2000).

There have been relatively few similar research projects. The most relevant are TRENEN (Proost and van Dender, 2000), which used a simple single link model of a number of cities to identify optimal combinations and the ISGLUTI project which studied, but did not optimise, land use and transport strategies (Paulley and Webster, 1991). No consultancy studies of individual cities are known which have explored the relative merits of different policy combinations in sufficient detail to determine the best combinations, largely because of the limits imposed by clients on the resources for policy analysis.

The presented methodology is a further development where we incorporate, in addition to the transport system, the development in land use over time. To be able to do so, we use time marching land use transport interaction models and simulate future development paths of cities over a 30 year period. An automated assessment of these development

paths is used to identify an optimal city specific policy package. The methodology presented is based on an ongoing UK research project, where it is applied and tested for eight cities. Beside the method we also show results of phase 1 where we have identified optimal transport strategies against a pre-defined objective function.

Section 2 describes the general approach, section 3 describes the appraisal framework and objective function used, section 4 describes the policy instruments, section 5 introduces the model used and case study results are presented in section 6. Finally section 7 draws conclusions and describes the next steps in our study.

The Integrated Approach

The integrated approach is designed to help city authorities to identify their city specific optimal land use and transport strategies to meet their future needs and targets.

The concept is to connect a state of the art transport policy appraisal framework with a dynamic (time marching) land use and transport interaction model and an automated multidimensional optimisation technique. This approach enables city authorities in collaboration with transport-planning experts to simulate future development paths of cities and regions and provide guidance for the implementation of optimal transport and land use policy packages. Figure 1 shows how the different parts are woven together and depicts at the same time the requirements of the integrated approach.

To be able to carry out the optimisation process a series of initial steps have to be done:

Optimisation Process

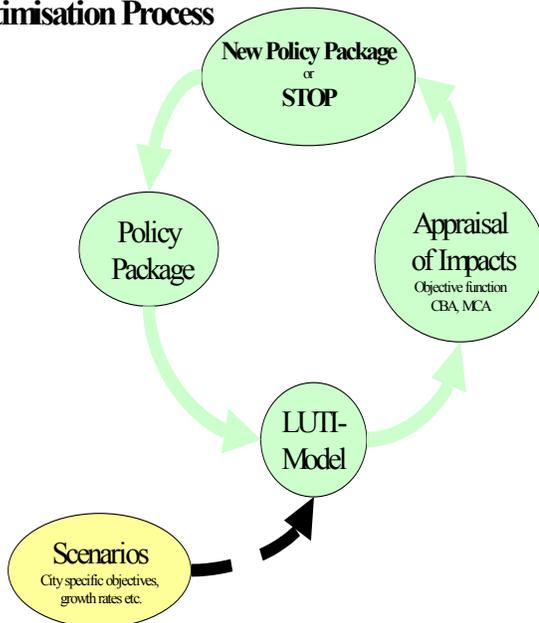


Figure 1: Optimisation Process

Set up process in close collaboration with the cities:

Firstly we have to identify the objectives and targets of the cities. Then we look for an agreement on a city specific appraisal of impacts and realise this through a translation of their objectives into a so called objective function (see section 0).

Then we define a set of policy instruments and their city specific ranges (see section 0). In the next step we define city specific scenarios concerning their objectives, growth rates, economic development etc. Based on that information we are able to set up the Land Use Transportation Interaction (LUTI) model. This model includes all city specific information, zoning system, inhabitants, workplaces, housing etc (see section 0).

Optimisation process: Once the set up is complete the optimisation process can begin, which is expressed by the inner loop of arrows. The loop “Policy Package – LUTI-Model – Appraisal of Impacts – New Policy Package” is carried out until no better policy package can be found. These iterations are the optimisation process. The number of iterations (= runtime of the optimisation) is influenced by the complexity of the appraisal method, the number of policy instruments and their spatial and temporal disaggregation.

In the project we use three different LUTI models (START/DELTA (Simmonds, 1999), SPM (Pfaffenbichler, 2001), TPM (TRL, 2001)) which operate at different levels of detail. The LUTI models provide information about land use and transport system developments for a 30 year period. This information will be used to appraise the impacts of the applied instruments against city specific objectives using a Cost Benefit Analysis (CBA) or Multi Criteria Analysis (MCA) based approach. Within this paper we only present the results for the SPM.

The Appraisal Framework

To be able to appraise the different transport strategies, a set of objectives against which the policies are appraised had to be defined. The objectives of all the cities are based on suggestions made in the UK Government's White Paper on the Future of Transport (DETR, 1998). Based on this, we agreed with our partner cities to use sustainability as an overarching objective, and formed six underlying policy objectives:

- economic efficiency
- liveable streets and neighbourhoods
- protection of the environment
- equity and social inclusion
- safety and severity of traffic accidents
- contribution to economic growth.

To be able to work with these six objectives we had to translate them into an objective function. The objective function tries also to balance the interests and needs between present and future generations (Minken et. al., 2002).

The current objective function (OF) used is based on former research work carried out in PROSPECTS (May et. al., 2002) and is implemented in all three models. The OF consists of an economic efficiency term (CBA part or core objective), a CO₂ costs term and a term for monetised values for local pollution and accidents. All these costs are discounted over a 30 year evaluation period. Additionally the needs of future generations are considered through a weighting mechanism (α - value) within the objective function.

In formal notation the OF used is:-

$$OF = \sum_t \alpha_t (b_t - c_t - I_t - \gamma_t g_t) + \sum_{it} \mu_{it} y_{it}$$

Where:

$$\alpha_t = \alpha \frac{1}{(1+r)^t} \text{ for all years between 0 \& 30 except year } t^*$$

t^* = the last modelled year (year 30)

r = discount rate

α = intergenerational equity constant, $0 < \alpha < 1$, to reflect the relative importance of welfare at present as opposed to the welfare of future generations, and:

$$\alpha_{t^*} = \alpha \frac{1}{(1+r)^{t^*}} + (1-\alpha)$$

b_t = benefits in year t and c_t = costs in year t , including user benefits, producer surpluses, benefits to the government, and external costs.

I_t = Investment.

γ_t = shadow cost of CO₂ emissions, reflecting the national CO₂ target for year t

g_t = amount of CO₂ emissions in year t

μ_{it} = shadow cost of reaching the year t target for sub-objective I

y_{it} = level of indicator i year t .

The user benefits for the households are calculated using the "rule of a half" or logsum formulas and including the benefits from land use (Minken et al, 2002). Producer surpluses are derived by annual revenue minus cost including taxes for all firms, operators and entrepreneurs.

The OF ranks all possible policy combinations in respect of their contribution to the overall goal of sustainability and is used as criteria for the optimisation process.

Policy Instruments

Based on interviews with city representatives during a series of EU-funded research projects a set of policy instruments were identified. Based on that information we developed the SPM model, which was able to simulate the impacts of the set of instruments listed in Table 1.

Instrument	Affects	Type	Bounds	Spatial	Comment
Public Transport					
New public transport services	TT	discrete	0/1	OD	Either built or not
Frequency changes	TT	continuous	-50% to +100%	All	Percentage change compared to do-min
Fare level	C	continuous	-50% to +200%	All	Percentage change compared to do-min
Private Car					
New roads	TT	discrete	0/1	OD	Either built or not
Road capacity	TT	continuous	-20% to +20%	All	Percentage change compared to do-min
Road charging	C	continuous	0 to 10 Euro	OD	Euro per trip into a defined area
Fuel Price	C	continuous	0% to +200%	All	Percentage change compared to do-min
Parking Charges	C	continuous	0 to 10 Euro	OD	
Non motorised modes					
Pedestrianised areas	TT	discrete	0/1	OD	
Land use					
Land use taxes	C	continuous	-5 to +10 Euro	by zone	Certain amount per built up space
Protection of certain areas	C	discrete	-5 to +10 Euro	by zone	

TT Travel time

C Costs

OD Origin-destination pair

Table 1: Policy instruments modelled in the SPM

The instruments can be classified either by mode (Slow modes, Public Transport or Private Car), their impact on generalised costs (travel time or cost), their type of implementation (discrete or continuous), or their impact on land use.

As can be seen we take into consideration three instruments for public transport. Two of them are continuous instruments (*fare* and *frequency* changes) and one discrete (*new public transport services*) which must be applied to the specific city on origin-destination pairs affected.

For private car we simulate the impacts of four different instruments. *New roads* is the counterpart to the *new public transport services* instrument above. It is a discrete instrument and has also to be implemented on origin-destination pairs affected. Under *road capacity* we assume low cost capacity changes like removal of on street parking or intelligent transport systems, etc. The instrument *road pricing* is implemented as a city specific cordon charge, the *fuel price* instrument is used to influence the cost for private car on a distance basis. Finally we simulate the impacts of city specific short- and long term *parking charge* changes.

For pedestrians we simulate the impacts of city specific *pedestrianisation* introduced at the zone level.

And finally there are two measures related to land use, changes in *land use taxes* and *protection of certain areas*. Both of them are used to influence the level and location of land use development.

The bounds for the different measures are chosen on one hand in regard to their technical feasibility (for example +/- 20% changes for low cost road infrastructure changes). On the other hand the boundaries have to be as wide as possible to enable some unconventional solutions (for example up to 10 Euros per hour for parking charges).

Common and city-specific implementation costs have to be assigned to all instruments mentioned above. These costs are used within the appraisal framework (see section 0) to assess the implementation and operation costs against the resulting benefits. Except for discrete instruments and fuel tax we allow different levels of implementation for peak and off peak. This enables us to identify optimal instrument levels for these time periods.

All the policy instruments can be implemented at any level within the defined upper and lower bounds at any point in time. For simplification the instruments were optimised for two years: the implementation year and a long run year. Between these two years the instruments are linearly interpolated. After the long run year the instruments are kept at a constant level.

In later research this specific model design enables us to investigate an optimal implementation sequence of various policy instruments.

The Sketch Planning Model (SPM)

The SPM is a strategic, interactive land-use and transport (LUTI) model. It was developed as a time-saving alternative to traditional four-step transport models. The SPM process is influenced through the use of several demand and supply-sided instruments whose impacts can be measured against targets of sustainability. The SPM assumes that land-use is not a constant but is rather part of a dynamic system that is influenced by transport infrastructure. Therefore at the highest level of aggregation the SPM can be divided into two main sub-models: the land-use model and the transport model (Figure 2). The interaction process is shown by the use of time-lagged feedback loops between the transport and land-use sub-models over a period of 30 years.

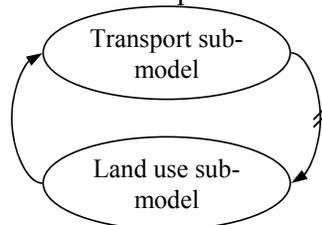


Fig. 2: SPM subsystem diagram on the highest level of aggregation

Two person groups, with and without access to a car, are considered in the transport model. The transport model is broken down by commuting and non-commuting trips, including travel by non-motorised modes. The land-use model considers residential and workplace location preferences based on accessibility, available land, average rents and amount of green space available. A rather high level of spatial aggregation is used in the SPM. In most case studies this means that the municipal districts are chosen as travel

analysis zones. The outputs of the transport model are accessibility measures for each zone while the land-use model yields workplace and residential location preferences per zone.

The interaction between land-use and transport modelling components is influenced through a set of policy instruments. Changes in the transport subsystem due to the application of an instrument cause time lagged changes in the land use system (Knoflacher et. al., 2000). For example new road infrastructure will change the location of housing and workplaces in the long term. These changes in land use feedback immediately and as time lagged reactions in the transport subsystem. For example a newly established enterprise zone causes an immediate change in travel demand and may initiate the development of a new public transport (PT) service in the long term.

The Case Study Results

As mentioned earlier eight cities are involved in this study. For four of them the SPM is available. These four cities are Oslo, capital of Norway, Vienna, capital of Austria, and for Leeds and Edinburgh, two main economic centres in the UK. The cities vary in size and population and in modal split terms.

City	population	area[km ²]	Modal split Ped	Modal split PT	Modal split PC	Car ownership per 1000 pop
Oslo (N)	396,974	454	17.0%	22.7%	60.3%	400
Vienna (A)	1,550,123	415	27.6%	27.2%	45.3%	354
Leeds (UK)	727,700	559	23.4%	23.9%	52.7%	307
Edinburgh (UK)	1,071,768	2305	22.1%	24.5%	53.4%	371

Table 2: Overview case study cities

As can be seen the modal split shares vary significantly. In Oslo for example just 17% of all trips are made by slow modes whereas in Vienna more than 27% of all trips are made using slow modes. The two cities from the UK have similar modal split figures; in both cities more than 50% of all trips are made by private car. In Vienna there is a very high share of environmentally friendly transport means (55% of all trips either slow mode or public transport) despite the high car ownership rate. One reason for the high share in Vienna is the public transport system: it is mainly based on tramway (233km) and underground (62 km). In the other cities the public transport system is mainly bus based.

Selected Results – Optimal Strategies

In the first phase of the project we calculated the optimal strategies using a common set of policies in all cities. The common set was chosen in collaboration with the cities to enable direct comparisons between the cities. The optimisation process applied was an unconstrained optimisation in that there are no financial constraints or performance targets. The lower and upper bounds of the common set instruments were defined as follows:

- Fares –50% to +100% for peak and off-peak
- Frequencies –50% to +200% for peak and off-peak

- Road Charging 0 to +10 Euro for a specified cordon

The instruments were introduced in year 2006 (implementation year) and then linearly increased/decreased till 2016 (long run year). The results of the optimisation process are shown in Table 3.

City	Fares*				Frequency*				Road Charging in Euro			
	peak		off peak		Peak		off peak		peak		off peak	
	2006	2016	2006	2016	2006	2016	2006	2016	2006	2016	2006	2016
Oslo (N)	-29%	-32%	-23%	68%	76%	93%	97%	178%	4.64	2.24	1.45	0.47
Vienna (A)	-35%	-44%	-49%	-50%	-3%	-5%	198%	198%	1.89	0.95	0.34	0.00
Leeds (UK)	-48%	-50%	4%	-34%	199%	186%	198%	200%	7.94	5.00	0.02	0.50
Edinburgh (UK)	-50%	-50%	-50%	-50%	31%	9%	22%	33%	4.05	2.34	0.08	0.16

Table 3: Optimal policy combinations * in % change from do-min

As can be seen in the table above an optimal strategy generally consists of a reduction of public transport fares. In all cities the optimisation process suggested a significant decrease in fares in peak and off peak. For frequency changes there is not such a clear picture. Here the optimisation process suggests for Vienna in the peak a minor reduction of frequency. This seems to be plausible since in Vienna the peak headway is 3 minutes for underground and 7 minutes for tramways. A slight reduction will lead to significant cost savings for operators in combination with marginal disbenefits for the PT users. In the other cities the optimal combination includes a slight increase of frequency in Edinburgh (31% and 9% peak and 22% to 33% off peak), an intermediate level of increase in Oslo, and a major increase in frequency in Leeds (to the upper bound of +200%). For the Road charging measure differing optimal values are derived. In all cities the optimal road charging value is higher for the peak period compared to the off peak period. The lower road pricing values in the off-peak are a feature of the SPM which assumes no congestion in the off peak period and therefore no time savings for highways. A redesign of the SPM is being considered to eliminate this effect. In all cities the optimal solution suggests starting with a higher value for road charging in the implementation year 2006 and then reducing it in the long run year 2016. This could be due to the alpha value and needs further investigation. Sensitivity tests for Edinburgh have shown that using a common value of 3 euros in both the short and long run years gives similar results in terms of the OF value.

Table 4 shows the detailed results for all optimal solutions separated by different transport system user groups:

City	User benefits			Operators		CO2 benefits	local pollutants	PVF	OF
	NM	PT	PC	PT	PC				
Oslo (N)	-611	3,891	-1,714	-1,124	1,480	9.3	337	355	364
Vienna (A)	-197	14,103	-1,090	-6,487	144	14.7	384	-7,749	872
Leeds (UK)	-352	6,553	-152	-951	302	-28.4	235	-830	861

Edinburgh (UK)	-225	4,447	-465	-3,067	324	23.7	203	-2,751	194
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Units Million Euro

NM.....Non Motorised

PTPublic Transport

PCPrivate Car

PVFPresent Value of Finance

OFObjective Function

Table 4: Economic evaluation

There are two main groups within the transport system: on one side the users and on the other side the operators & providers, both groups disaggregated by mode. The user benefit (if the sign is positive, disbenefits if the sign is negative) consists of two main sources. The first source is related to direct money savings/cost induced through the suggested policy. For example a reduction in fares will lead on the transport user side to money savings while on the other hand the operator will lose money. The second source of user benefits/disbenefits is related to travel time savings/losses caused by the optimal policy package. As can be clearly seen the slow modes are the losers in all of the suggested strategies.

The big gainers are the pt-transport users caused on one hand by significant fare reductions and on the other hand by the increase in frequency and the related time savings (mainly waiting times). The situation for car users must be seen in a more differentiated way: on one hand some drivers lose money because of the implementation of a road pricing scheme (peak and off peak) on the other hand they gain some time benefits due to higher travel speeds caused by a reduced demand for car. But as can be seen in Table 4, the gain in time savings is not enough to outweigh their losses in money terms.

On the operator side the pt-operator loses in all cities because of the fare reduction and frequency increase (less revenue and higher operating costs) but the road operators gain some money caused by the introduction of road pricing. More detailed results show a loss of fuel duty to the government from reduced fuel consumption.

In the column headed CO₂ benefits we display the relative discounted benefits related to CO₂ emissions. The suggested strategies reduce in all cases the negative impacts of CO₂ except in Leeds (The 200% increase in public transport frequency leads to an increase of CO₂ emissions compared to the do-min scenario).

The column headed local externalities shows the impacts of the optimal policy combination on accidents and local pollutants (VOC, NO, etc.). As can be seen the suggested optimal solutions reduce the negative impacts of these local externalities in all cities and thus generate benefits for society.

Under the column headed PVF the present value of finance is displayed. This value summarises the revenues and costs for operators/providers and the government and indicates whether the suggested policy combination needs additional funding (if negative) or produces a surplus. The negative PVF values imply that the suggested combination is

not financially viable and therefore may not be acceptable. We will take this into consideration in phase two of the project, where we can constrain solutions to result in a positive PVF.

The last column in Table 4 displays the final result, the value of the objective function as described in section 0. It is difficult to spot a pattern here, the OF value seems to depend on the population and the resulting policy combination, but it appears that the higher the population and the higher the frequency changes the higher the OF value.

Table 5 shows the modal split values which provide information on how the suggested policy combinations perform in transport terms. To facilitate the comparison between the different scenarios the modal split figures are displayed for the do-min scenario and the optimal scenario:

City	Commuting			Non working		
	NM	PT	PC	NM	PT	PC
Oslo Do-min (y1)	22.2%	34.8%	43.0%	21.5%	27.7%	50.8%
Oslo Do-min (y30)	21.2%	32.2%	46.6%	18.4%	27.5%	54.1%
Oslo opt (y30)	19.1%	38.7%	42.3%	16.6%	34.0%	49.4%
Vienna Do-min (y1)	25.8%	37.2%	37.0%	28.1%	24.5%	47.4%
Vienna Do-min (y30)	21.1%	35.5%	43.4%	24.7%	24.7%	50.6%
Vienna opt (y30)	19.1%	43.2%	37.6%	19.1%	40.0%	40.9%
Leeds Do-min (y1)	19.8%	28.8%	51.4%	24.9%	22.0%	53.2%
Leeds Do-min (y30)	15.8%	25.8%	58.5%	21.6%	25.2%	53.2%
Leeds opt (y30)	11.6%	40.0%	48.5%	16.1%	37.4%	46.5%
Edinburgh Do-min (y1)	18.0%	34.0%	48.0%	24.0%	20.0%	56.0%
Edinburgh Do-min (y30)	16.1%	34.3%	49.6%	22.8%	21.7%	55.5%
Edinburgh opt (y30)	14.7%	40.2%	45.1%	20.3%	26.9%	52.7%

NM.....Non Motorised
PTPublic Transport
PCPrivate Car

Table 5:Modal split figures year 30 Do-min and Optimum scenario

In the first row for each city the do-min modal split figure for the first year is displayed. In the second row the modal split figure for year 30 of the do-min scenario is displayed and in the third row the modal split value for the optimal strategy in year 30. If we compare the modal split values in year 1 with the modal split values in year 30 for the do-min scenario it can be seen that there is a systemic shift from pedestrians to motorised transport means. This may be caused by the fact that the present and future land use development takes place in the outer zones of the cities, which suits motorised transport means, and hinders development of dense city structures, where walking is the appropriate transport mode. Urban sprawl and decentralisation are the logical result.

If we compare the year 30 modal split figures between the do-min scenario and the optimal scenario, we see that the modal split share of the slow modes goes down further in all cities and for all purposes (commuting and non-working trips). The reason for that is that all suggested policy packages improve the attractiveness of motorised modes (especially public transport) compared to the slow modes. An attractive public transport system competes not only for private car users but also for slow modes users. It is

questionable if this is a desirable development from a sustainable point of view of future transport systems.

If we look at the development of the modal split figures for PT in the do-min scenario the following trends can be seen. The modal split figures for PT either decline slightly (Oslo commuting, Vienna commuting, Leeds commuting) or stay stable (Edinburgh commuting). For the non-working trips the modal split figures are either stable (Oslo, Vienna) or indicate a slight increase (Leeds and Edinburgh).

If we compare these trends with the optimal scenario the modal split figures for PT go up in all cities and for all purposes. It can be said that the optimal scenario is PT friendly, but at the expense of slow modes and private car.

Finally we look at the development of private car modal split. Again in the do-min scenario the modal split for cars goes up in all cities and for all purposes (except for Leeds non working trips). Looking at the optimal scenario a reduction of this increase can be found. In all cities the modal split figures for private car are lower compared to the do-min scenario; in most cases the values for car usage are lower than in the “do-min year-1” scenario.

In summary it may be said that there is a system-wide trend towards motorised transport means in the do-min over time. None of the optimal solutions found so far can reverse this trend. But implementation of these optimal strategies can ease the burden from car use by reducing the modal split share of private car.

Conclusions and Further Steps

We have developed a method which can automatically produce optimal strategy combinations for any given objective function.

The use of a time marching transport model which includes all transport modes can help to reveal shortcomings in existing land use and transport strategies (as shown by the reduction of slow mode share in the do-min scenario).

The results derived so far for case study cities show that in general public transport fares should be reduced, and the public transport frequencies should be significantly increased in peak and off peak (except for Vienna where the service level is already very high). It is recommended in all cases to introduce at least a peak period road charging scheme. Additional sensitivity tests to prove the stability of these recommendations have to be carried out.

Further tests will include optimisations using the full set of policy instruments listed in Table 1 and will show their contribution to an increase in the objective function.

Additionally we plan in co-operation with city representatives to identify barriers, which hinder the implementation of the suggested optimal strategies. We will discuss how to

overcome some of these obstacles and define constraints, will be reflected within our models. This process should enable us to identify acceptable strategies. After re-running our model we will present these acceptable strategies to the cities again. Finally we will focus on land use measures and their impacts and contribution to optimal and acceptable strategies. These results will then form the basis for the final consultation with cities.

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Planning Involvement Process: A Critical Element in Establishing Transit Centers

Paul Steffens

No abstract available.

Guiding Future Investments in Minnesota's Transportation Systems and Services: A Performances-Based Approach to Long-Range Planning

Jacqueline Corkle

No abstract available.

Alternative Approaches to Special Market Travel Analysis

Eric Pihl, *Federal Transit Administration*

Abstract. The representation of 'special' or unconventional travel markets is an important aspect of travel or ridership forecasting that often receives inadequate attention relative to the treatment of conventional markets. Special markets may include travel to special events (e.g. sporting events), travel to special facilities (e.g. airports), or circulation trips (e.g. lunchtime trips). Many producers of transit forecasts have discovered that special markets can represent a non-trivial component of travel demand and their exclusion may contribute to possible underestimates or distortion in the estimated travel demand for conventional travel markets.

Although most conventional travel models may be estimated to represent non-conventional markets as an explicit purpose, home interview survey data often lack a sufficient level of detail or observations necessary to estimate or calibrate models that reasonably represent observed travel patterns. The nonrecurring nature of non-conventional travel often compounds the difficulty in representing special markets for a typical weekday.

Alternative approaches for estimating special market travel demand will be described that focus on "off-model" treatment of special travel markets. A prototype spreadsheet model that incorporates inputs to conventional travel models - including demographic and travel costs associated with each transportation alternative - will be demonstrated. The discussion will include real-world examples of output measures and their usefulness in both project and system level planning.

The Travel Time Index—A Versatile Tool for Mobility Measurement

David Schrank, *Texas Transportation Institute*

Abstract. As the population living in urban America increases, urban areas are forced to pursue many programs and new projects to improve mobility. A method is needed to demonstrate the benefit derived from these transportation projects and programs to a variety of non-technical audiences.

The Texas Transportation Institute has developed a methodology to measure mobility from the macroscopic areawide level down to the corridor level. This methodology uses the travel time index (TTI) to show the extent to which mobility is affected by the slower speeds associated with heavy traffic and incidents during peak travel conditions. The TTI shows the additional amount of time that is required to make a peak trip versus the same off-peak trip. The information required for the TTI calculations are either collected data or estimates of the peak period and freeflow (off-peak) operating speeds for both the freeways and principal arterial streets in the urban area and the miles of travel on these facilities.

Because of its simplicity, the travel time index is a valuable planning tool for any urban area regardless of size. The methodology has been used to measure mobility levels on the arterial street system in Grand Junction, Colorado. It has been used to show the effectiveness of high-occupancy vehicle lanes in the Katy Freeway corridor in Houston, as well as the combined effect of a high-occupancy vehicle lane and light rail line in the Santa Fe Arterial corridor in Denver. The same methodology can be used to measure the effectiveness of transit, signal coordination on arterial corridors, freeway ramp metering, incident management programs, and many other improvements both at the corridor and areawide levels.

Situational Sketch Planning: A Model of The Model

David B. McBrayer, AICP, *Parsons Brinckerhoff*

Abstract. Although various generic sketch planning methods are commonly used to evaluate the ridership and related effects of public transportation improvements, it is possible in some cases to extract data from an area's mode choice model and use it to construct simplified analyses of transit route alternatives. This approach is applicable when a significant number of route variations should be examined, but time and funds are not sufficient to allow analysis by means of the formal mode choice model. An advantage of the method is that results can be compared directly with existing formally-generated forecasts.

The method can be used to generate estimates of transit user time saved as well as new riders attracted to transit, and the modeling results feed logically into other analyses such as operating and maintenance cost effects and transit vehicle fleet size. With the addition of simple estimates of capital cost and information about other issues, an essentially complete evaluation of an alternative can be obtained.

The purpose-built analysis is constructed within one or more interrelated computer spreadsheets, and is consequently transparent and flexible in its structure and use. The author addresses this subject by describing a specific example taken from recent study of light rail transit alternatives. The discussion includes some alternative approaches that can be taken, as cross-checks or as constrained by data availability, the nature of the transit alternatives being examined, or other factors.

GPS Measurement of Travel Times, Driving Cycles, and Congestion

Philip Bullock and Peter Stopher, *The University of Sydney*; and
Chester Wilmot, *Louisiana State University*

Abstract. In the past few years, various types of GPS devices have been developed for use in connection with travel surveys of various types. This paper describes applications in Sydney, Australia, in which the GPS devices have been used to collect data on automobile trips within the urban area, with the goal of developing information about travel times, driving cycles, and the incidence and severity of congestion.

The first issue in applying GPS to the measurement of travel times along specific corridors is to develop a process for sampling segments of streets and then to determine how to combine the segment data to provide data on corridor levels of service, as well as updating link travel times. The paper describes the procedure used to develop the samples for two exercises – one in which measurements were made to compare the travel times on a toll road to those of the surface streets with which the toll road was intended to compete; the second in which measurements were made to update the travel times on major arterial routes through a region within Sydney for the purposes of developing plans for alternative congestion relief.

The paper describes the results of the data collection in both cases, estimates the sampling errors on segment, link, and corridor travel times, and compares the results with posted speed limits and more traditional speed data. In addition, the paper shows how the data can also be used to identify the extent and severity of congestion along these corridors, and how the data can also be used to determine more information about the driving cycles for vehicles driven along these routes. It is shown that the GPS provides an accurate and inexpensive method to determine speeds, acceleration, deceleration, and the incidence of congestion. The samples, which are not large, are shown to provide accurate data for different time periods of the day, and for each link along the arterial route.

Using Real-Time GPS Data to Develop Roadway Travel-Time Profiles for Transportation Modeling

David A. Faria, P.E., *Technology Solution Providers*

Abstract. The quality of peak or 24-hour travel forecasts used for short- and long-term transportation planning is based, in large part, on the average travel times and speeds of roadway facilities. These travel times and speeds are usually based on estimates generated from expensive regional travel-time surveys.

In recent years, transit agencies have invested millions of dollars in technology-based systems like Automatic Vehicle Location (AVL) systems, which are installed on transit vehicles. In most cases, travel time data collected is used for bus schedule and route adherence, and on-time performance. This study looks at alternative uses of travel time and speed data continuously collected from transit vehicles. As part of this effort, the relationship between bus travel speeds and average roadway travel speeds was evaluated and studied. This presentation will describe the process used to develop roadway speed or travel-time profiles based on real-time transit AVL data. The results of this study effort are very encouraging. This methodology can be successfully used in urban and rural areas, which have invested in transit-based AVL systems. The utilization of transit data for roadway-based planning purposes is a new and innovative approach, which maximizes the use of available resources.

Global Positioning Systems (GPS) for Supplying Travel Related Data to MOBILE6

Srinivas Varanasi and Chester Wilmot, *Louisiana State University*

Abstract. MOBILE6 is a software program designed by U.S. Environmental Protection Agency (EPA) to estimate current and future vehicle emissions under different conditions. MOBILE6 is the latest in a series of MOBILE models and is the first update in MOBILE after the release of MOBILE5b in 1996. The MOBILE6 model calculates in-use fleet emissions of hydrocarbons (HC); carbon monoxide (CO); and oxides of nitrogen (NO_x) generated by gas or diesel-fueled cars, trucks, buses, and motor cycles. MOBILE6 can break down emissions by roadway type, time of the day, vehicle category, and other characteristics that allow detailed modeling of specific local situations. It incorporates many new features, including new input and output options that make it more flexible and effective. These new input options in MOBILE6 create a significant new information burden on states preparing submissions for State Implementation Plans (SIP) and conducting conformity analyses. The input requirements for MOBILE6 can be broadly classified into four types: external conditions; vehicle fleet characteristics; vehicle activity data; vehicle gasoline specifications. Out of these input requirements, supplying data and vehicle on external conditions gasoline specifications is relatively straightforward. So the primary concern in supplying input data to MOBILE6 will be on data regarding 'vehicle fleet characteristics' and 'vehicle activity data'.

Traditionally, these data are supplied through vehicle registration records, personal travel surveys and estimates from travel demand models. However large errors can be generated using these methods. The research reported in this paper deals with a proof of concept study using Global Positioning System (GPS) instruments in vehicles to supply vehicle fleet and vehicle activity data input to MOBILE6. The concept is that a sample of vehicles are recruited in an area and fitted with GPS instruments to record vehicle activity. The GPS data has important information like 1. Position of the vehicle (Latitude and Longitude). 2. Time of the day. 3. Distance and time of travel. 4. Speed of the vehicle etc. The GPS data are transferred into a GIS, which has functional classification of the roadways, in the area. Using the features in GIS, the GPS data is queried to convert into the required MOBILE6 form. Data on vehicle characteristics are collected at the time of fitting the GPS instruments to the respective vehicles. The information is combined into a single file and analyzed to produce sample values of travel characteristics such as: Vehicle Miles Traveled (VMT)- by functional class, speed of the vehicle, vehicle class and time of day; Vehicle soak times; Age distribution of vehicles by vehicle type; Annual mileage accumulation rates; Vehicle starts per day; Week day and weekend trip length distributions etc.

The results from the GIS software are expanded to represent the whole population of the study area. Data from 104 households, surveyed over seven days in Lexington, Kentucky were used to test the concept. Results from the study were compared with the MOBILE6 default values.

MOBILE6 is a software program, designed by U.S. Environmental Protection Agency (EPA), to estimate current and future vehicle emissions under different conditions. The primary objective of the MOBILE model is to develop emission inventories for State

Implementation Plans (SIP) and for conformity determinations. MOBILE6 incorporates many new features from former MOBILE models including many new input options. As they are extensive, the new input options in MOBILE6 create significant new information burden on states, preparing submissions for SIP and conformity purposes. Vehicle fleet characteristics and vehicle activity data are among the most demanding inputs, because they are required at such a detailed level. Major input requirements that come under these two categories include annual mileage accumulation rates and Vehicle Miles Traveled (VMT) by facility type, vehicle class, speed interval, and time of the day. EPA provides national default values for MOBILE6 input requirements but recommends that local data be used wherever possible.

Traditionally, data on vehicle activity are supplied by travel demand models, traffic count data, instrumented vehicle studies and personal travel surveys. However there is always a question of accuracy of these data sources because these methods are not exclusively developed for air quality modeling purposes and are seldom accurate enough at the detailed level required in emissions modeling. Developing accurate travel related input data for air quality models like MOBILE6 is becoming a major challenge for the transportation planners involved in air quality modeling. Research is ongoing in this field and there is a keen interest to test the use of Global Positioning System's (GPS) data as an alternative means of estimating vehicle activity. More accurate and extensive travel information, which can be obtained by GPS data, makes it an attractive alternative for this kind of data acquisition. However, this field is new and the concept of using GPS instruments to obtain data for air quality models like MOBILE6 has not been fully tested.

The purpose of this study is to test the feasibility of using a sample of vehicles equipped with GPS to supply input requirements for MOBILE6. Instead of conducting its own GPS survey, this study makes use of already existing survey data. More details of the data are described in the 'Data' section. The study investigates supplying two major input requirements, namely annual mileage accumulation rates and VMT by facility type. MOBILE6 requires data for 28 vehicle classes. However in this study, the data is limited to Light Duty Gasoline Vehicles (LDGV) and Light Duty Gasoline Trucks (LDGT1) classes only. However, the same procedures may be adopted in obtaining the data for other vehicle classes. Finally, the required sample size of GPS equipped vehicles to obtain estimates of adequate accuracy is estimated.

Background

The EPA provides national default values for all the input requirements of MOBILE6. However, they suggest that local agencies should use the local data wherever possible. While preparing default values for mileage accumulation rates, the EPA used data from travel behavior surveys. Specifically, they used the 1995 Nationwide Personal Transportation Survey (NPTS), for LDGV class, and the 1992 Truck Inventory and Use Survey for LDGT class of vehicles (Jackson, 2001). While preparing the default values for VMT and speed distributions, EPA used the data from both travel demand models and traffic counts. Five different urban areas were selected, out of which results from three cities were obtained from travel demand models and those of the other two were obtained from traffic count data. Although all the above cities have different types of road networks

and functional classes, EPA used these merged data to represent national default values (EPA, 2001).

The Highway Performance and Monitoring System (HPMS) provides data of vehicle use from traffic counting in each state. These data can be obtained from FHWA and can be used in obtaining VMT distributions. However, the EPA recommends that local count data should supplement HPMS data to obtain more representative values (EPA, 1999). Areas with available Travel Demand Models can directly use estimated link volumes to provide local input data. However, there are some limitations to this method. Travel demand models cannot give vehicle classifications. The speed estimates of the travel demand models are also notoriously unrealistic. In addition, the intra-zonal trip data and the ramp travel are not usually available with this data source (EPA, 1999). Even though there are some limitations with these data sources, EPA developed its national default values for travel related data, using these two methods, minimizing the limitations.

It is apparent from this background information, that travel-related data to the MOBILE6 model could possibly be better supplied using observed data from a travel behavior survey. GPS is an emerging technology which provides increased spatial and temporal data on travel. There has been considerable interest in using the GPS technology for travel surveys in recent times, despite its complications and technical problems (Stopher, *et al.*, 2003). Significant difficulties with recruiting the households were observed by Stopher, *et al.* (2003) in a GPS pilot survey done in Sydney, Australia. Research by Wolf, *et al.* (2003) done on a GPS survey in California indicates that GPS has great potential to enhance travel surveys. The survey was conducted in three different regions, and GPS VMT values were compared with regular CATI modeled estimates. It was found that trip underreporting in CATI modeled estimates occurred in Alameda and Sacramento regions. However, to their surprise there was slight trip underreporting in GPS values in the San Diego region. A similar study by Pierce *et al.* (2003) reported considerable trip underreporting with regular travel surveys compared to GPS survey values.

Data

The GPS data collected as part of the Lexington Area Data Collection Test was used for the analysis in this research study. The Federal Highway Administration (FHWA)-sponsored Lexington study was considered to be the first study to collect in-vehicle GPS data. The GPS data was collected in Lexington, Kentucky, over a survey period of seven days with 100 household participants (Battelle, 1997). Each vehicle was provided with a GPS instrument, and the data was collected over the entire survey period. Along with the primary driver other drivers in the households were also allowed to use the vehicle provided with the GPS instrument.

The study represented the first attempt to match GPS data with recall data. They found that they were unable to match 55-60% of the total trips. Several issues were identified as factors for this high level of mismatching. Possible omission of equipment use or malfunction of the equipment, variations in processing the obtained raw data and respondent rounding inaccuracies were considered to be some of the possible causes for this high level of trip mismatching (Battelle, 1997).

This analysis deals with the map-matched trip files, resulted from a map-matching analysis process. The map-matching analysis was performed over the Lexington data, by software developed by TransCore. In this map-matching analysis the collected GPS points were used to identify the specific roadway nodes and links that were traveled in the Lexington area network (Battelle, 1997). The results of the map matching analysis (referred to as 'processed data' hereafter) allowed a more accurate description of the trip distance based on the link length contained in the database.

The processed GPS data, resulted from the map matching analysis contains valuable travel related information for the present analysis purpose. Some of the information in the processed data include, day of the travel, time of the day with an accuracy of 1 second, link ID, distance traveled within that link, travel time, speed, latitude and longitude, user ID, trip number, trip purpose, and the location of the trip. Even though the processed data is a better representation of the collected GPS points, it needed some modifications and adjustments to use it in the present analysis.

First of all the processed data was viewed for consistency by overlaying the GPS observations on a street map and by careful review of the data files. Any inconsistencies were investigated and corrections were made wherever possible. Because of the data mismatching problems, matched data for all the households was unavailable. Out of the 100 households, data from 80 households were found to be useful for this analysis. In most cases, processed data from all seven days of the survey period were not available.

As mentioned earlier, the present study deals with supplying annual mileage accumulation rates and VMT by facility type data for input to MOBILE6. There is not much difference between annual mileage accumulation rates and VMT, except that they are two different ways of representing vehicle travel. Annual mileage accumulation rates are broken down by vehicle age and vehicle class, whereas VMT is specified by facility type, vehicle class and hour of the day.

Annual Mileage Accumulation Rates

The annual mileage accumulation rate represents the total annual travel accumulated per vehicle of a given age and vehicle category (EPA, 1999). In the processed GPS data file, distance values are available in feet for all data records. The total travel by each vehicle is obtained by simple summation of all the distance values. Each vehicle's data could be distinguished from the other vehicles, based on the 'User ID'. Each number in the 'User ID' column showed the household ID and the driver number together.

To obtain annual mileage accumulation rate values in MOBILE6 format, the vehicle age and vehicle type information is also needed. Household information like vehicle age, vehicle type, number of drivers etc. was also collected at the time of recruitment and stored in a separate file. This external data was joined to the processed GPS data file using the 'User ID' as key.

Vehicle ages were distinguished into ages 1-25 with age 25 representing all vehicle models of 1971 and earlier. The Lexington study was conducted in 1996 and hence all the vehicles with 1996 as the vehicle model year were considered to be one year old. The vehicle year

1996 was considered as the ‘calendar year’ for the present study. All vehicle ages were determined based on the following simple equation

$$\text{Vehicle age} = (\text{Calendar Year} - \text{Vehicle Model Year}) + 1$$

In the Lexington study, all the vehicles were classified into five vehicle types. These were automobile, van, utility vehicle, pickup truck and other type of truck. The first three vehicles were considered as constituting the Light Duty Gasoline Vehicle (LDGV) class used in MOBILE6. The last two were considered Light Duty Gasoline Truck 1 (LDGT1) class as designated in the vehicle categories in MOBILE6.

Total mileage values were estimated for each vehicle and extrapolated to annual mileage values based on the number of days of travel observed. As mentioned earlier data was generally not available for all 7 days of travel for each vehicle and hence the number of days of travel differed from household to household. Annual mileage rates were calculated using this equation: Annual Mileage = {(total travel in survey period in miles)/number of days of travel}*365.

The obtained annual mileage accumulation rates were classified into the two vehicle classes and 25 vehicle ages. Results for LDGV and LDGT1 classes are shown in table 1. Default values suggested for MOBILE6 are included for comparison purposes. Values are not shown for vehicle ages 19-25 because no vehicles of these ages were present in the GPS data.

VMT By Facility Class

This input requirement for MOBILE6 requires hourly VMT data to be supplied for each of the four facility classes, under each of the 28 vehicle types. The four facility classes include freeways, arterials, local roads and freeway ramps, respectively. Under each of the facility classes, 24 hourly VMT values need to be supplied, starting from 6 a.m. onwards. Travel between 6 a.m. and 7 a.m. was considered as 1st hour of travel; and travel between 5 a.m. and 6 a.m. was considered as the 24th hour travel. The EPA supplies the same set of default values for all the vehicle types for this input requirement. Hence, all vehicle classes were combined together in the present analysis. This also alleviates error introduced due to small sample size in the Lexington study.

For classifying the VMT data by facility class, the GPS data needed to be analyzed in a GIS environment. TransCAD GIS software was used for this specific purpose. First of all, the GPS data was geo-coded in TransCAD using the latitude and longitude values. The processed GPS data file was then opened as a ‘dataview file’ in TransCAD. The GPS data file consisted of all the travel information except the facility class information. To add the facility class information to the GPS dataview file, a street network with facility class information was needed. The Lexington street network provided by the Battelle team consisted of all the facility class information except the ramp information. However a problem with this street network was that this network was a very small network and there were many out-of-area trips. To overcome these problems, the present study used a bigger street network that came with the GIS software. This street network consisted of very detailed facility class information. However it was not in the required MOBILE6 format.

The detailed facility classes were aggregated into the required 4 facility classes and this information was added to the GPS data view file.

To transfer the facility class information into the GPS data, the 'Overlay' feature in TransCAD was used. Using this feature, a separate data view file containing all the features of the GPS layer and the functional classification information of the street network was obtained. However, this procedure is not accurate under certain conditions. The 'Overlay' feature associates the street network properties to the GPS layer, based on the bandwidth provided by the user. If the bandwidth selected for this purpose is too narrow, GPS observations can be lost. Broad bandwidths on the other hand will assign the information of surrounding streets to the GPS layer. This may result in assigning some of the local streets surrounding a freeway, with a freeway functional class. To minimize these problems, the street network was divided into four parts, based on the facility type. All the freeways, arterials, local streets and freeway ramps in the street network were established as separate layers. This allowed the individual facility class networks to be overlaid separately with the GPS layer, with different bandwidths. After experimenting with different bandwidth values, a bandwidth of 0.2 miles was selected for freeways and arterials, and a bandwidth of 0.1 mile was selected for local streets and ramps. This minimized some part of the error; however the selection of some roads along with the ramps was not rectified. In such cases, wherever possible, the roads that were wrongly assigned with ramp classification were selected by TransCAD's 'Select by shape' feature and assigned with appropriate facility class information.

After attaining the GPS layer with functional classification associated with it, the VMT values were distributed based on the hour of the day. Four GPS layers were obtained after using the above procedure; one for each functional class. The hour of the day values were assigned to the GPS data file and the hourly VMT values were estimated under each of the functional class. For each hour of the day, the sum of all the VMT fractions by functional class must equal one. The results are shown in table2.

Statistical Tests

The differences of the GPS and default values in the individual cells were used in finding out the statistical significance at 95% confidence limit. First of all, the Annual mileage accumulation rate results were tested. A total of 15 individual values in each of the age group were present in the results. A student T-test is applied on the differences as shown in tables 3 and 4. The null hypothesis is formed such that the mean value of the difference is greater than or equal to 1000. The results are also tabulated. Results show that both the vehicle classes have different values than those of the default values. The same T test is applied on the VMT by facility class values. The null hypothesis is formed such that the mean value of the difference is greater than or equal to 0.1. It is found that the arterials and locals have different values from those of the default values. Tables 5 and 6 show these results.

Sample Size Estimation

In this section, an effort is made to estimate the sample size for a future GPS survey based on the present analysis. The sample size estimated in this process could be useful for

obtaining vehicle activity data to MOBILE6, using a GPS survey. The variance of the observed mileage accumulation values in the individual cells were used to estimate a sample size that would be required to estimate mean values at the 95% level of significance. The sample size estimation procedure is described below.

An acceptable standard error of mean was calculated from the specific confidence limits and level of significance. In this analysis, sample sizes, for individual vehicle age classes were estimated at 95% level of significance. Out of the estimated sample sizes in each vehicle age category, the largest value must be considered as the required sample size. The following steps were undergone, for estimating sample sizes in individual vehicle age categories.

Let the acceptable percentage error in the estimate of each category value be 'd'
The tolerable deviation is then $d * m$, where 'm' is the sample mean of individual vehicle category.

The standard error of estimate (S.E.E) is $\frac{S}{\sqrt{n}}$, where 'n' is number of observations over which standard deviation is calculated.

Let the maximum acceptable error equal to $(S.E.E) * Z$, where 'Z' is 1.96 for a 95% level of confidence.

Estimate the new sample size 'N' for an infinite population from the following equation.

$$\text{Sample size } N = \left(\frac{1.96 * S}{d * M} \right)^2$$

Tables 7 to 11 show the calculations involved in the sample size estimation. Assuming a maximum percentage error of 10% of the mean values, a sample size of 754 vehicles could be more or less sufficient for obtaining vehicle activity inputs to MOBILE6.

Limitations

1. The Lexington data used in this study has a lot of missing data. Subsequently, some data in the sample could not be utilized. This reduced a small sample of data to an even smaller sample which made estimation difficult.
2. In the Lexington study, GPS instruments were fixed in the primary vehicles (vehicles that make most of the trips) of a household only. Use of this data might bias the VMT estimates because the sample is no longer a random sample of all types of vehicles.

Conclusions and Recommendations

This research effort is focused on a highly emerging issue: the possibility of the GPS data for supplying inputs to air quality modeling

The research study is a proof-of-concept study in which the possible use of GPS data is tested for two of the major input requirements to MOBILE6. Data for annual mileage accumulation rates and VMT by facility class input requirements were extracted from the GPS data, using a GIS platform.

The annual mileage accumulation rates are obtained for two vehicle classes, namely LDGV and LDGT1. In both the cases, the distributions of the individual values are considerably different from those of the national default values. However, statistical tests are unable to establish a significant difference. The variation is expected to be the product of the small sample size.

Results of VMT by facility class obtained in this study raise an important issue. It shows that local values can differ considerably from the national default values. In the present analysis a lot of local travel is recorded while very little arterial travel is found compared to the national values. The reason is that there are few arterials in Lexington area. An estimate of the sample size needed for a GPS survey was made using the survey data. A sample size of 1000 was found to be appropriate based on the results of present research study for accurate results at 95% level of significance and a permissible 5% error.

It appears that GPS can be an effective tool to collect travel related data for use in vehicle emission modeling. In recent years this technology is emerging a variety of applications. The use of GPS data for supplying input data to air quality models such as MOBILE6 appears feasible and a viable alternative to other methods of obtaining data input for such models.

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Table 1: Annual Mileage Accumulation Rates

Vehicle Age	LDGV			LDGT1		
	sample size	GPS	Default	sample size	GPS	Default
1	4	8957	14910	1	12281	19496
2	12	9724	14174	1	13594	18384
3	8	8921	13475			
4	4	8800	12810	1	26216	16267
5	5	19679	12178	2	11538	15260
6	4	6781	11577	3	10756	14289
7	7	13226	11006	1	9769	13352
8	4	9661	10463	3	8749	12451
9	4	11203	9947	1	26863	11584
10	5	10159	9456	2	5457	10752
11	3	11722	8989			
14	2	7930	7723			
17	1	6151	6636	1	5197	5909
18	1	14177	6308			
Average		10506	10689		13042	13774

Table 2: VMT by Facility Type

Hr. of the Day	Freeway		Arterial		Local		Ramp	
	GPS	default	GPS	default	GPS	default	GPS	default
1	0.41	0.39	0.18	0.46	0.33	0.12	0.08	0.03
2	0.43	0.34	0.14	0.50	0.40	0.13	0.03	0.03
3	0.42	0.34	0.15	0.50	0.39	0.14	0.04	0.03
4	0.48	0.35	0.12	0.49	0.38	0.13	0.02	0.03
5	0.45	0.35	0.18	0.50	0.35	0.13	0.03	0.03
6	0.46	0.33	0.17	0.51	0.34	0.13	0.03	0.03
7	0.45	0.32	0.17	0.52	0.34	0.13	0.03	0.03
8	0.45	0.33	0.16	0.51	0.36	0.13	0.03	0.03
9	0.55	0.33	0.00	0.51	0.42	0.13	0.03	0.03
10	0.44	0.32	0.16	0.52	0.36	0.13	0.03	0.03
11	0.43	0.33	0.16	0.51	0.39	0.14	0.02	0.03
12	0.43	0.31	0.15	0.52	0.39	0.14	0.04	0.03
13	0.41	0.30	0.18	0.54	0.38	0.14	0.03	0.03
14	0.43	0.31	0.15	0.53	0.39	0.14	0.02	0.03
15	0.44	0.33	0.17	0.51	0.35	0.13	0.03	0.03
16	0.42	0.34	0.19	0.50	0.36	0.13	0.02	0.03
17	0.44	0.38	0.13	0.46	0.40	0.13	0.03	0.03
18	0.42	0.41	0.19	0.44	0.38	0.12	0.01	0.04
19	0.43	0.43	0.12	0.42	0.41	0.12	0.04	0.04
20	0.42	0.44	0.10	0.40	0.42	0.12	0.06	0.04
21	0.46	0.46	0.08	0.39	0.45	0.11	0.01	0.04
22	0.43	0.46	0.12	0.39	0.43	0.11	0.03	0.04
23	0.36	0.45	0.28	0.40	0.36	0.11	0.00	0.04
24	0.43	0.42	0.10	0.43	0.36	0.11	0.11	0.04
Average	0.44	0.37	0.15	0.48	0.38	0.13	0.03	0.03

**Table 3: Differences of GPS values from default values
Student T Test on Annual Mileage Accumulation Rates**

Age	LDGV	LDGT1
1	5953	7215
2	4450	4790
3	4554	0
4	4010	9949
5	7501	3722
6	4796	3533
7	2220	3583
8	802	3702
9	1256	15279
10	703	5295
11	2733	0
14	207	0
17	485	712
18	7869	0

Ho: $U_o \geq 1000$

Ha: $U_o < 1000$

Number of values N =15

Df = 14

Upper fractile of student t-test = 1.761

Table 4: Results

Average	3181.467	3900.8
stdev	2630.124	4318.937
T	3.518913	2.849556
Result	Reject Ho	Reject Ho

Student T Test on VMT by Functional Class Values

Table 5 : Difference of GPS values from default values

Hr.	Freeways	Arterials	locals	Ramps
1	0.02	0.28	0.21	0.05
2	0.09	0.36	0.27	0
3	0.08	0.35	0.25	0.01
4	0.13	0.37	0.25	0.01
5	0.1	0.32	0.22	0
6	0.13	0.34	0.21	0
7	0.13	0.35	0.21	0
8	0.12	0.35	0.23	0
9	0.22	0.51	0.29	0
10	0.12	0.36	0.23	0
11	0.1	0.35	0.25	0.01
12	0.12	0.37	0.25	0.01
13	0.11	0.36	0.24	0
14	0.12	0.38	0.25	0.01
15	0.11	0.34	0.22	0
16	0.08	0.31	0.23	0.01
17	0.06	0.33	0.27	0
18	0.01	0.25	0.26	0.03
19	0	0.3	0.29	0
20	0.02	0.3	0.3	0.02
21	0	0.31	0.34	0.03
22	0.03	0.27	0.32	0.01
23	0.09	0.12	0.25	0.04
24	0.01	0.33	0.25	0.07

Ho: $U_o \geq 0.1$

Ha: $U_o < 0.1$

Number of values N =24

Df = 23

Upper fractile of Student t test = 1.714

Table 6: Results

Average	0.07	0.33	0.25	0.00
stdev	0.07	0.07	0.03	0.02
T	-1.99	16.90	21.92	-21.45
Result	Do not Reject	Reject	Reject	Do not Reject

Table 7: Sample Size Estimation for Annual Mileage Accumulation Rates

veh_age	Mean (M)	stdev (S)	0.05*M	Sample size (N)
1	9621.67	3305.18	962.17	45.33
2	10021.45	5082.15	1002.14	98.80
3	8921.42	3886.97	892.14	72.92
4	12283.35	8852.19	1228.34	199.52
5	17352.64	9703.58	1735.26	120.13
6	8484.96	2852.30	848.50	43.41
7	12793.43	10538.57	1279.34	260.68
8	9270.06	4091.73	927.01	74.84
9	14335.04	7183.06	1433.50	96.46
10	8815.81	3231.76	881.58	51.63
11	11721.67	2654.54	1172.17	19.70
14	7929.64	6576.29	792.96	264.22
17	5674.13	674.12	567.41	5.42
18	14176.54	0.00	1417.65	0.00
		85th percentile = 202.57		
		Tolerable deviation = 10%		
		Confidence level = 95%		

Table 8: Sample Size Estimation for VMT by Facility Class (Freeways)

Hour	Mean(M)	Stdev (S)	d*M	Sample size (N)
1	24177	23950	1208.85	376.98
2	18805	19608	940.25	417.67
3	23803	26259	1190.15	467.53
4	12594	18837	629.70	859.43
5	11499	12736	574.95	471.26
6	17038	18618	851.90	458.71
7	18975	23793	948.75	604.01
8	17352	18899	867.60	455.71
9	16002	19906	800.10	594.47
10	17046	17384	852.30	399.55
11	18333	14529	916.65	241.28
12	20887	18810	1044.35	311.56
13	14900	13009	745.00	292.84
14	11841	13006	592.05	463.47
15	13105	14852	655.25	493.41
16	12153	13468	607.65	471.79
17	12373	16874	618.65	714.49
18	11112	13608	555.60	576.12
19	8723	8903	436.15	400.18
20	11814	12344	590.70	419.40
21	11198	7750	559.90	184.01
22	9199	6307	459.95	180.58
23	9240	7170	462.00	231.32
24	18470	30045	923.50	1016.54
	Largest 85th percentile = 599			
	Tolerable error d = 10%			
	confidence level 95%			

Table 9: Sample Size Estimation for VMT by Facility Class (Arterials)

Hour	Mean(M)	Stdev (S)	d*M	Sample size (N)
1	12048	9668	602.40	247.37
2	8054	8998	402.70	479.49
3	9794	10626	489.70	452.20
4	3892	3819	194.60	369.88
5	5533	9925	276.65	1236.09
6	6822	8748	341.10	631.69
7	7586	9488	379.30	600.95
8	6294	8735	314.70	739.92
9	6963	9833	348.15	766.11
10	6594	7272	329.70	467.22
11	7173	6506	358.65	316.04
12	7214	7259	360.70	388.97
13	7605	8018	380.25	427.02
14	4535	5442	226.75	553.19
15	6727	10775	336.35	985.61
16	6797	8846	339.85	650.69
17	5480	6282	274.00	504.83
18	5972	11733	298.60	1482.83
19	4341	3603	217.05	264.64
20	2818	1865	140.90	168.26
21	3368	1723	168.40	100.54
22	2464	136	123.20	1.17
23	7226	8762	361.30	564.84
24	6626	8155	331.30	581.91
	85th percentile = 754.32			
	Tolerable error d = 10%			
	confidence level 95%			

Table 10: Sample Size Estimation for VMT by Facility Class (Local roads)

Hour	Mean(M)	Stdev (S)	d*M	Sample size (N)
1	19579	15827	978.95	251.03
2	15247	15572	762.35	400.71
3	18064	19377	903.20	442.04
4	9079	10661	453.95	529.70
5	8515	6548	425.75	227.17
6	10896	11352	544.80	416.99
7	12592	14050	629.60	478.27
8	11659	13619	582.95	524.18
9	11044	9928	552.20	310.44
10	11981	12381	599.05	410.24
11	14448	12663	722.40	295.10
12	15862	16434	793.10	412.37
13	12239	10514	611.95	283.50
14	9595	11556	479.75	557.23
15	10037	9024	501.85	310.53
16	8770	9189	438.50	421.74
17	9728	14243	486.40	823.51
18	8868	10148	443.40	503.06
19	8400	8785	420.00	420.18
20	10533	10950	526.65	415.18
21	11018	7720	550.90	188.60
22	9166	6352	458.30	184.49
23	9223	7145	461.15	230.55
24	15525	24944	776.25	991.70
	85th percentile = 527.21			
	Tolerable error d = 10%			
	confidence level 95%			

Table 11: Sample Size Estimation for VMT by Facility Class (Ramps)

Hour	Mean(M)	Stdev (S)	d*M	Sample size (N)
1	8987	9591	449.35	437.53
2	2999	3336	149.95	475.35
3	3226	4268	161.30	672.41
4	2043	3651	102.15	1226.87
5	1432	1185	71.60	263.06
6	2257	2782	112.85	583.66
7	1889	1729	94.45	321.84
8	1710	1571	85.50	324.24
9	1804	1587	90.20	297.30
10	2188	3701	109.40	1099.15
11	1654	1440	82.70	291.18
12	2727	2772	136.35	396.94
13	1888	1555	94.40	260.60
14	1582	1992	79.10	609.08
15	1788	1271	89.40	194.12
16	1483	2563	74.15	1147.43
17	1956	2098	97.80	441.96
18	633	376	31.65	135.54
19	2139	2709	106.95	616.18
20	1848	2519	92.40	713.78
21	597	198	29.85	42.26
22	546	359	27.30	166.08
	85th percentile = 707.57			
	Tolerable error d = 10%			
	confidence level 95%			

Turning Transportation Planning Data Into Effective Web Sites

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Abstract. The web offers a unique opportunity for State Departments of Transportation and planning agencies to publicize to a large audience the results of transportation and travel demand models.

While desktop GIS applications are used by engineers to produce such models, they require a learning curve and domain knowledge in order to be used effectively. On the other hand, Web applications can provide a simple user interface that allows all GIS users and decision makers to quickly get answers to their geographic queries and easily perform drill down analysis.

For the past few years, Caliper Corporation has been developing an integrated software environment that significantly simplifies the process of developing transportation models and turning them into attractive interactive web sites. The process can be as simple as creating a thematic map and selecting the appropriate web application template that will be used to display the map on the web.

In this presentation, we will demonstrate the process by providing examples of transportation web sites developed using our technology. We will use the examples to discuss the many technical issues that are involved in turning transportation models into highly effective web sites, and we will conclude by discussing how the Internet can be used in the future to provide additional access to transportation models and GIS analysis tools and data.

In this paper we compare and contrast the functions of desktop geographical information systems (GIS) applications vs. web mapping applications in the specific context of transportation studies, and we discuss some of the benefits as well as the technical issues that arise when transferring features from a desktop application to a web application. We will use case studies about linear referencing, routing and demographic analysis to illustrate the points we will make.

Engineers use GIS and transportation planning applications to analyze road network data, solve routing problems and predict changes in travel patterns and the utilization of the transportation system in response to changes in demographics and transportation supply (see [1] for a review of some desktop GIS applications used for linear referencing and dynamic segmentation).

Usually, the functions offered by desktop applications are geared towards expert users. The applications allow engineers to create and edit geographic databases (e.g., route systems), and join them to tabular information such as pavement conditions, traffic accident reports along mileposts, and demographic tables. While desktop applications

enable engineers to perform complex geographic editing functions and run interactive queries by location, they require technical knowledge and skills in order to be used effectively.

Until the advent of the World Wide Web, the most appropriate way of disseminating to a large audience the information gathered by transportation studies has been via static reports, tables and map images created with the GIS desktop applications. The use of interactive reports and interactive maps that allow users to perform queries by location has been limited to the users that have access to the GIS desktop applications and to the underlying data.

In the last few years, we have witnessed technical advances in web-based interactive mapping. The web sites listed in [2], [3] and [4] provide many significant examples of accessing and querying geographic data via a simple web browser interface connected to GIS application servers. The Web offers a unique opportunity for State Departments of Transportation and planning agencies to disseminate to large audience interactive results of transportation studies. Unlike a static report or map image, an interactive map allows anybody connected to the Internet to query the result of a study by location and perform drill down analysis, such as getting traffic accident reports for specific segments of a route system.

A web mapping application is a very effective way to visualize large quantities of data sets for a large audience. In many cases, it is desirable to disseminate the data very fast, as soon as it is available, without requiring users to download the data to their desktop and to use specialized software for viewing the data. For example, the Census 2000 has released the County-To-County Worker Flow Files [6]. These data contain the number of workers 16 years old and over who commute to work. The counts give the number of workers traveling within or between counties in the 50 states and the District of Columbia, plus travel to workplaces outside the U.S., such as Puerto Rico or a foreign country.

To quickly display and query this large data set (127,798 non-zero flows between pairs of 3,294 counties), we developed the web mapping site www.caliper.com/countytocounty. The map on that web site displays desire lines and tables for any selected county. To display the flows to and from any county in the United States, the user can simply click on a county area. The flows are displayed on the map using a scaled symbol theme (see Figure 1), and in a table below the map (see figure 2). To reduce clutter, only flows of 50 workers or more in or out of the county are shown on the interactive map.

Figure 1: In the County-to-County worker flow web site, the user can choose the info (i) tool and then click anywhere on the map to display the home-to-work travels to and from any county in the United States.

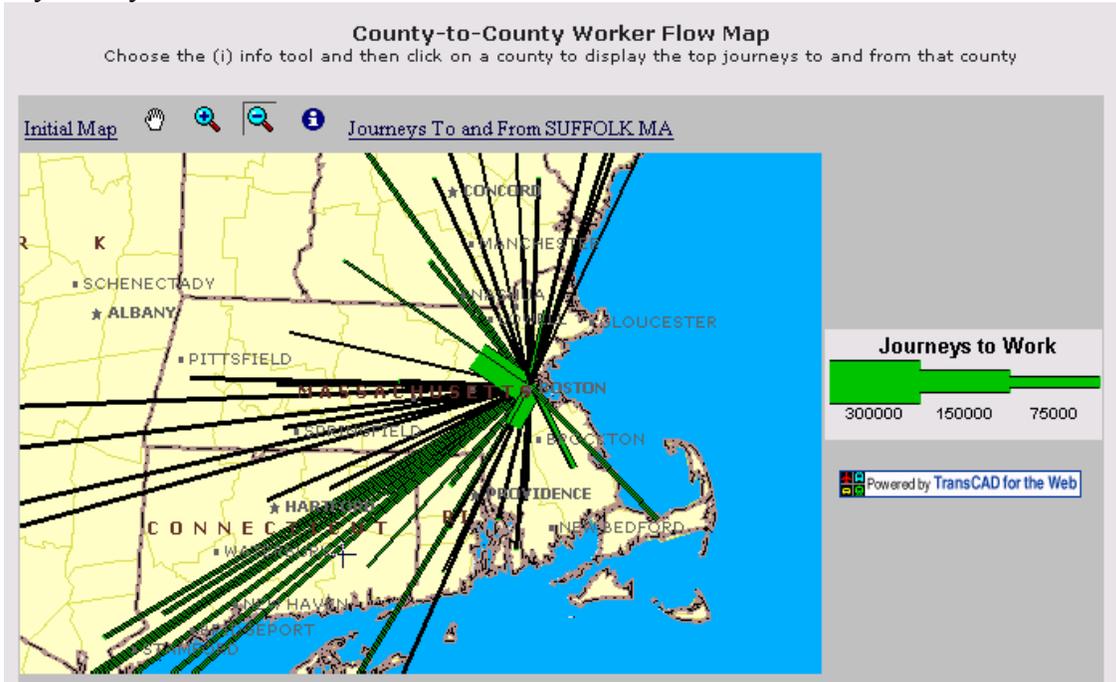


Figure 2: Below the map, the worker flow data is also presented as a table.

Journeys To and From SUFFOLK MA (Threshold = 50)

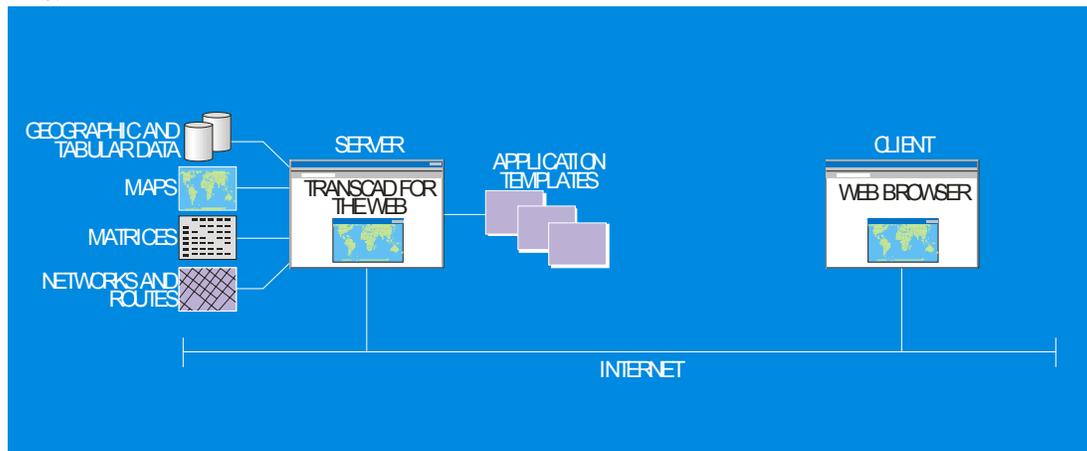
County A	County B	Journeys from A to B	Journeys from B to A
ANDROSCOGGIN ME	SUFFOLK MA	86	18
BARNSTABLE MA	SUFFOLK MA	2,767	237
BELKNAP NH	SUFFOLK MA	156	--
BERKSHIRE MA	SUFFOLK MA	97	46
BRISTOL MA	SUFFOLK MA	11,103	1,409
BRISTOL RI	SUFFOLK MA	216	35
CARROLL NH	SUFFOLK MA	126	--
CHESHIRE NH	SUFFOLK MA	85	--
CHITTENDEN VT	SUFFOLK MA	76	28
COOK IL	SUFFOLK MA	110	186

Desktop Applications vs. Web Applications

From a software architecture perspective there are important technical differences between a desktop GIS application and a web mapping application. Knowledge about these differences will enable us to understand and overcome the technical challenges in designing effective web applications and decide which functions are appropriate to transfer from a desktop GIS application to a web mapping application.

In contrast, in a typical web application session many concurrent users interact with one application server via a sequence of web pages and map images that are dynamically generated. Users connect to the application server via a web browser such as Internet Explorer, and there is no GIS application or geographic data installed on each user personal computer or local area network. In the rest of the paper, we will limit our discussion only this “thin client” software architecture, where most if not all of the computations are executed on the application server (see figure 3).

Figure 3: In typical web application architecture, all of the computations are performed by the GIS application server (to the left of the figure). Many users connect to the application server via the Internet and a thin client – e.g., Internet Explorer (to the right of the figure). The web application server sends to the browser all the information needed to display a map, including a map image file and one or more HTML tables and input forms.



The web application user interface provides a limited number of tools when compared to the desktop application. This is due to two constraints. Firstly, the target audience for the web application is as large as possible, and includes non-expert users. The web application user interface provides only the essential display and reporting tools that can be used with minimal training or knowledge of the underlying route system data structures employed by the software. Secondly, since the application server executes most of the computations the web application implements the set of functions of the desktop application that can be executed efficiently in a multi-user environment.

When a user clicks on the map or fills an input form in the web page, the application server performs the appropriate selection in the database stored in the server local area network and displays the results as HTML tables, images and maps. The web page

displayed in the browser stores only the map image and the user session parameters that are needed by the application server to restore the user session when the next page is requested.

Managing Multiple User Sessions in a Web Application

In general, there are three approaches in storing the user session information in the web application server. The approaches can be combined and are presented here in an increasing level of technical complexity.

Approach 1 – Storing Session Information In a Web Page

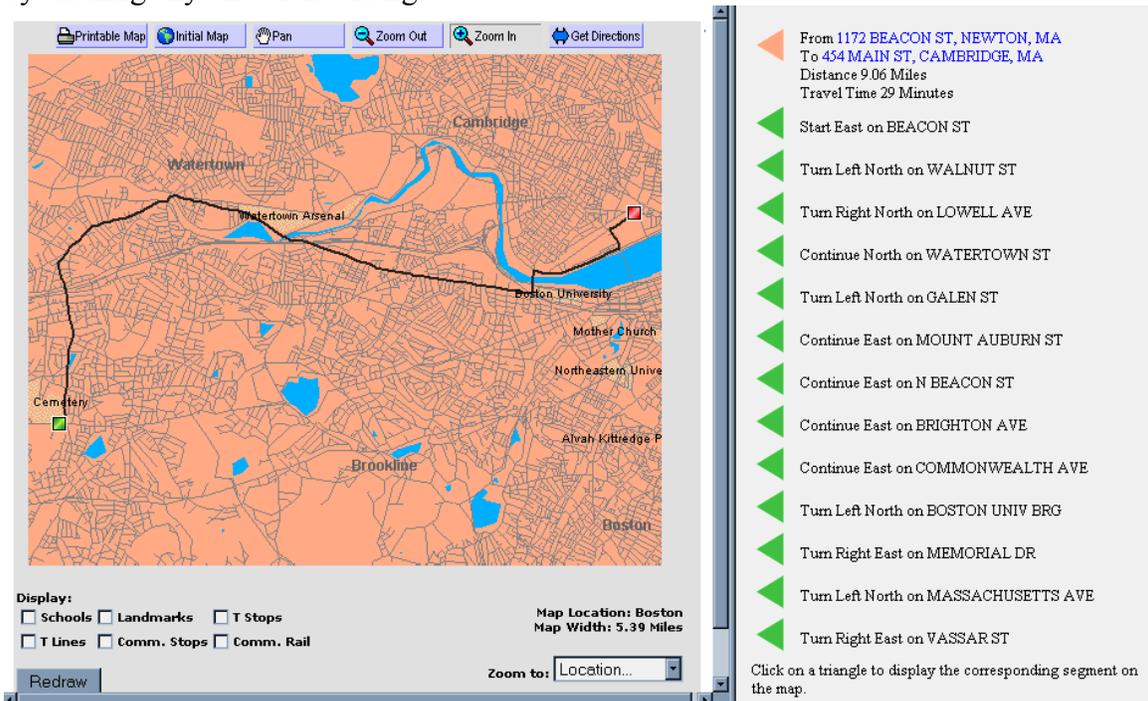
The first and simplest approach is to store all of the information needed to create the map and the user selection in the web page. This is an appropriate solution if the information needed to restore the map is limited (e.g., map extent, origin, destination, and route name), and the amount of time it takes to restore the user selection in the memory of the application server is negligible. In this case, the page control flow for every page includes restoring the user selection and map extent, drawing the map or the chart, and releasing the user selection. This approach has the advantage of being scalable to an unlimited number of users. The application server does not maintain a session in memory for each user connected to the web application, and a web page can be served by any one of a number of servers that stores a copy of the web application. If the number of concurrent users increases, the increase in page requests can be handled by adding web application servers with a copy of the web application.

Approach 2 – Storing Session Information in Persistent Objects

The second approach is to compute some of the information needed to draw a map once and then store it a persistent fashion in the application server file system or as an object in the application server database system. This approach is being used by our direction-giving web applications. When a user asks for directions from an origin to a destination, the directions are computed once by the application server and then stored as an XML file in the server file system (*figure 4*). The web page stores information about the origin, destination and a unique identifier for the directions stored in XML format. When the user pans or zooms to a specific segment of the directions, the application server restores the directions by reading them from the XML file.

In this second approach the application server does not maintain a specific session in memory for each user connected to the web application, and all session-specific information (e.g. directions) are stored in persistent objects or files by the application server. This approach scales well to multiple users because persistent objects (e.g. XML files or database objects) can be shared across a number of application servers; however it is appropriate only if the time it takes to store and reload objects from the local file system or database system is negligible.

Figure 4: In the direction giving web application, the user can select an origin address and a destination address. The application server translates the input addresses to geographic locations and computes the directions a series of line segments in the road network. The directions are stored as an XML file and displayed as an HTML table to the right of the map image. The directions are restored from the XML file into the server memory when the user zooms or pans on the map image or zoom in to a specific segment by clicking any one of the triangles.



Approach 3 – Storing Session Information in Memory

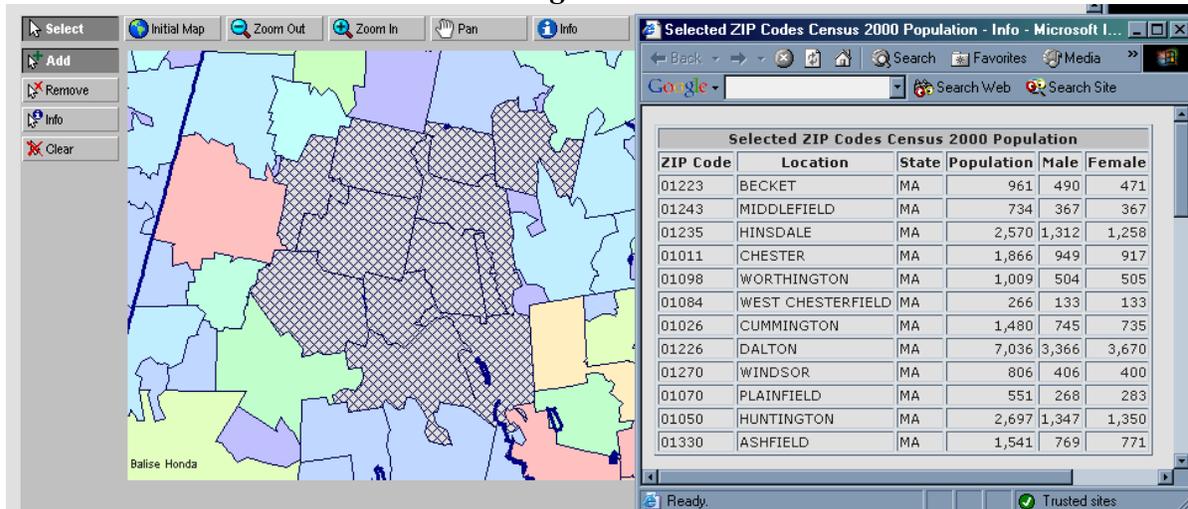
The third approach is to maintain a pool of user sessions in the application server memory space. Using this approach, the web page stores the individual user unique session identification number, and the application server stores all the information needed to restore the map in memory. This approach is taken in one of our web applications to enable the user to add or remove ZIP Codes from a potentially very large selection set and then display aggregate information about the selection set specific to each user – e.g., total population in the selected area (**figure 5**). In this approach, the application server maintains a pool of selection sets with time stamps.

The selection sets can be stored in the server memory for a limited amount of time. As soon as a user clears the selection set or when a time-out occurs the selection set can be used by another user. This is appropriate when it would take too much time to store and retrieve a potentially large selection set from a file or external database for every page, but it requires that a specific server is assigned to a user selection set until the user discards the selection set or a time-out occurs.

Figure 5 shows, in this web application, the user can use the selection tool in the upper left corner to add or delete ZIP Codes from the current selection. The application server maintains a selection set of ZIP Codes for each specific user. When the user clicks on the

Info button in the selection toolbox, the application server collects the demographic information (Population, Male, Female) for the selection set and displays it in a pop-up window.

Figure 5



Editing and Personalizing Routes Online

The computational power, memory and disk space of mapping servers increases substantially every year. As a consequence, it is now practical to store and edit geographic data for hundreds of individual users on one mapping server. Authenticated users can log in to a server and set their own map display setting preferences, as well as review and edit their own personal geographic data.

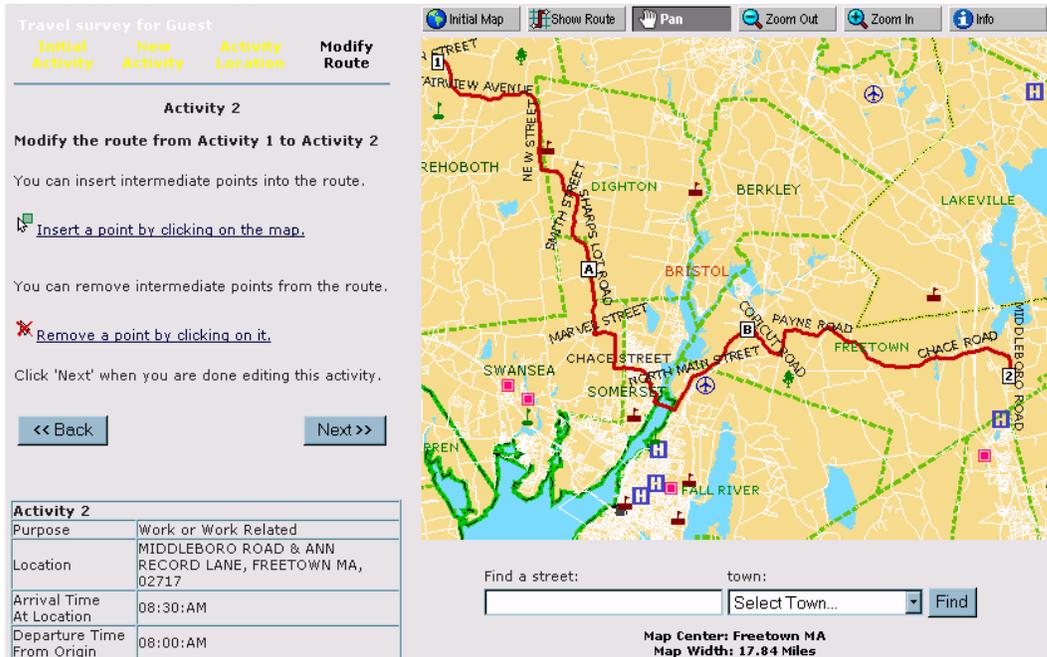
The web mapping software must be carefully designed to manage multiple user data sets at the same time. In a load-balanced distributed architecture, individual user preferences and data will be stored in their own protected folders, and the folders may be physically stored on a separate machine from the web mapping servers, to increase performance and security.

The geographic data collected from each user can be aggregated and analyzed by transportation planning software, simplifying substantially the process of collecting data for transportation models. For example, travel surveys are necessary for building accurate transportation demand models. Typically, home-to-work travel data are collected on paper forms and booklets, the data is transferred to databases by hand, and eventually the database columns are associated to attributes on road network geographic layers that are used for estimating the models. This is a very time consuming process that provides limited data sets and that is prone to errors and omissions, especially when travel demand models need to be specified at the street address level.

An online travel survey service is a cost-effective alternative to paper surveys (see figure 6). Users can log in to a web site and fill a travel survey in stages. Typically, a user records their demographic profile and their home-to-work travels by activity. For each activity, the user enters all of the data that she would otherwise enter in a paper survey. Each activity correspond to a location (e.g., a street address), a purpose (e.g., at home, at work,

school, shopping, etc) and a time of day.

Figure 6: Unlike a paper travel survey, the on-line travel survey includes an interactive map. The map is used to specify the precise street address location of each activity, and to edit the route from one activity to the other. The screenshot displays how to edit a route between two activities. To the left, the user can choose an action (e.g., adding a route stop, modifying a route). If the user chooses to modify the route between two activities, she can either insert or remove intermediate points by clicking anywhere on the map to the right of the figure. The mapping server responds by redrawing the route to correspond to the user's choices.



Unlike a paper survey, users can specify the exact geographic location for each activity using an interactive map. The interactive map is also used to edit the route taken from one activity to the other. Initially, displays the route between activities based on the shortest path between them. While filling the survey, the user is always able to edit the route by inserting and deleting intermediate points, thus recording the actual route that was taken, rather than an ideal route.

An online travel survey offers two main advantages over paper data collection. Firstly, it is possible to collect data from a large number of users in a very short time and at a fraction of the cost of collecting data on paper. Secondly, since the interactive map includes the road network geographic layer that will be used to estimate the travel demand models, the data collected is immediately associated to the planning network nodes and segments. Thus data entry inaccuracies are minimized.

The ability of editing and personalizing routes for each individual user is a function that is not limited to collecting travel survey data. It is also a key feature that can be used by route delivery and fleet management systems, public transport route planning systems, and carpooling systems.

Extending the Functionality of Web Applications

Because the application server must maintain or restore each user specific session data structure with one of the three approaches described above, it is clearly beneficial that each page is processed as fast as possible. As a consequence, not all of the functions of the desktop application may be appropriate for being implemented in the web application. For example, we would consider appropriate to implement a function that always take a limited amount of time, between 1 and 5 seconds. If a reporting or display function takes more than 5 seconds, it might be better to compute the report offline, and deliver it to the user via email.

However, at least three considerations lead us to believe, as do many others, that the number of functions that can be implemented in a web application will increase significantly in the next few years. Firstly, the computational power of the hardware increases and the cost decreases substantially every year. The performance of a GIS application depends on many features including CPU clock speed, memory size, data bus size, and file input/output throughput. All of these features tend to improve substantially from one year to the next. Secondly, the generic user interface technology that can be embedded in the web browsers allows developing very rich graphical interfaces that go well beyond raster map images and HTML tables. Soon, users will be able to manipulate directly in the web browser vector images that overlay points, lines and area layers via the standard scalable vector graphics language (SVG) [5]. Thirdly, the number of people connected to the Internet with high-speed connections increases steadily every year, making it viable to transfer high-resolution images with printer-ready quality and large amount of geometric vector data between the web browser and the application server.

In summary, a web mapping application can implement a number of functions in order to present results of transportation studies in a very graphically rich and interactive presentation. In this paper we tried to illustrate how the web application control flow is substantially different from the control flow in a desktop application. As a consequence, the functions of a web mapping application must be designed carefully, sometimes from scratch, in order to support multiple user sessions in the most efficient manner.

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An Expert System for Projecting Traffic on Arizona's Rural State Highways

Thomas A. Cooney, *Wilbur Smith Associates* and Joseph Flaherty, *Arizona Department of Transportation*

Abstract. Traffic counts and forecasts directly impact almost all core business activities of a State Department of Transportation (DOT). Like most State DOTs, the Arizona Department of Transportation (ADOT) regularly collects traffic count data for the State Highway System and has done so for many years. The 6,000 mile Arizona State Highway System has been divided into more than 1,100 traffic count sections. ADOT currently has 1-27 years of count data for each count section.

As is the case for most State DOTs, ADOT's historical count data is far from perfect. Vandalism, mechanical problems, construction related disruptions, budgetary constraints and other factors have resulted in significant amounts of non-typical, bad or missing data.

Even so, ADOT is dependent upon historical traffic count data to forecast future traffic on rural portions of the Arizona State Highway System. Traditionally ADOT staff and consultants have prepared forecasts for individual traffic control sections on an "as needed" basis. Each time a forecast was generated the preparer was responsible for reviewing, identifying and rectifying inappropriate historical data (if any), and deciding what mathematical procedure would be used to generate the forecast. Recognizing the potential problems associated with this "ad hoc" approach, the Arizona Department of Transportation has recently developed an automated "expert system" to project future traffic on the rural State Highway System based on historical count data.

More specifically, ADOT's Expert System Projections (ESP) software is a tool that provides a statistics-based procedure for identifying and eliminating certain kinds of bad count data, and standardized mathematical procedures for generating traffic forecasts. Linear regression is used to forecast traffic on rural sections having sufficient count data. A "peer group" based forecasting procedure is used on rural sections for which insufficient count data is available. ADOT's ESP software also stores, displays and reports urban model-based forecasts for State Highways sections within the major metropolitan areas.

This paper:

- Briefly summarizes the procedures used by ADOT to collect traffic count data.
- Describes the types of problems and issues associated with the ADOT's historical count data.
- Presents the "expert system" rules and procedures adopted to deal with the data issues and standardize the forecasting procedures.
- Discusses the lessons learned in developing and using the ESP procedures, as well as anticipated enhancements.

Ports to Plains Environmental Resources Baseline: The Digital Document

Ashley McLain, AICP and Andrew Poth, *Hicks & Company Environmental*

Abstract. As part of the environmental component of the Ports to Plains Feasibility Study, Hicks & Company created a digital baseline document to present the environmental information in a clear graphical and narrative format. Accomplishing this objective in a 100 percent paperless document required Hicks & Company to design a digital document that integrates GIS and documentation software into an interactive, dynamic, and user-friendly information tool.

The Problem: The project study area is a broad corridor that extends from Denver, Colorado to Laredo, Texas and covers more than 62,000 square miles. The satellite imagery, GIS data layers, and narrative and tabular information available for this region includes more than *seven gigabytes* of environmental data. Hicks & Company's challenge was to present all this information in an easy to install, easy to operate, and easy to understand digital format.

The Solution: The Hicks & Company team was faced with a series of technical and design problems that included achieving compatibility of cartographic projections, color-balancing and compressing the data down to usable file sizes, and enhancing the interoperability of GIS and document software packages.

The Benefits: The resulting digital document is a prototype that represents a breakthrough in the communication of complex environmental information. As a widely available information resource, it has tremendous potential to *streamline* the environmental clearance process for major projects benefitting the public. The digital format will save time and money in data collection, analysis, and presentation of technical alternatives. Subsequent users can adapt the digitally preserved information to produce planning and compliance documents. High quality documents and strong public presentations can enhance the credibility of the project development process for major infrastructural projects.

CTPS Truck Trip Demand Model Innovations

Lawrence H. Tittlemore, Ian E. Harrington, and David S. Kruse, *CTPS/RMDG*

Abstract. The Regional Model Development Group (RMDG) of the Central Transportation Planning Staff (CTPS), the technical staff of the Boston (MA) Metropolitan Planning Organization (MPO), has recently completed a new truck trip demand estimation model. This new modeling approach provides a way to estimate or predict the major elements that compose the commercial vehicle portion of highway traffic. Specifically, the new model addresses the 10 vehicle classes considered as “trucks” in the FHWA physically-defined Scheme F Vehicle Classification. The major innovative features of our new truck modeling approach are the following:

- **Behavioral.** The model is based upon functional usage categories which capture relatively homogeneous patterns of truck operation and are tied to regional socioeconomic characteristics.
- **Tour-Based.** The model differentiates between truck trip tour ends and their intermediate starts and stops in order to impose a tour-like form on the pairing of truck trip ends.
- **Integrated.** The model is sensitive to changes in a specific set of interacting variables which are internally consistent and externally constrained. The variables include sector employment and population, truck ownership and operational characteristics, highway network truck restrictions, link truck volume counts, and intra-regional and inter-regional truck travel demand.

The model development effort was undertaken without the conduct of a major commercial vehicle survey. Support was drawn, instead, from already existing data resources. Sources included TIUS (now VIUS), Massachusetts Registry of Motor Vehicle files, and existing published truck production and attraction rates. These existing sources were then supplemented by specifically-focused telephone and travel-intercept surveys and video data capture. These specific-purpose approaches provided information used to quantify key behavioral relationships.

The underlying premise of our modeling approach is that overall truck travel demand can be divided into relatively identifiable and homogenous functional usage categories. This is similar to the relatively homogeneous trip purposes that are used for person travel demand estimation. In the final model formulation, nine truck functional usage categories were included. Each of the nine is comprised of relatively similar travel characteristics. Among these characteristics are tours per day, trips (legs) per tour, and trip length frequency. Within the modeling process, a series of relationships were established among firm employment, firm truck ownership/usage, and physical type and usage category of truck. These relationships are expressed in terms of both FHWA physical vehicle classes and the new CTPS usage categories. This correspondence made it possible to validate and, where necessary, to adjust our new travel demand matrices through use of trip table estimation techniques. In this way, we adjusted our initial demand levels for four time slices of the day and night to observed truck volumes from counts conducted on links of the highway system. CTPS has now incorporated this new modeling technique as the truck component in our overall operational travel demand model.

An Innovative Approach to Truck Modeling

Paul Agnello, *Baltimore Metropolitan Council*; Jocelyn Jones, *Baltimore Metropolitan Council*; William G. Allen, Jr., P.E, *Transportation Consultant*

Abstract. A Federal Highway Administration freight analysis forecasts that freight tonnage and truck VMT will double in the next twenty years. Interest in modeling truck traffic will, therefore, increase in response to increasing truck traffic in many areas. The traditional approach to creating a truck model has been to conduct a survey on truck movements to use to develop a model of truck trip rates, distribution patterns, and routes. This approach is generally not feasible, however, due to the difficulty and high cost inherent in conducting a statistically valid truck survey. An innovative, faster, less costly approach to developing a truck model has been developed using a technique called “adaptable assignment.”

Adaptable assignment is a practical method of synthesizing a trip table from count data. Detailed classification count data was available at over 600 locations throughout the BMC modeled network. An initial model was created using parameters from another urban area. This initial trip table was modified by the adaptable assignment process, to produce a new table whose assignment much more closely matched the count data. The resulting trip table was systematically compared to the initial table to understand the differences. Numerous adjustments were then made to the initial model to reflect those differences. An improved method of estimating external travel was also developed.

The final model consists of standard generation and distribution steps, a table of calibration adjustments, and an assignment process that specifically recognizes trucks. The calibration adjustments are applied to all future trip tables. This process was applied twice, to develop separate models for Medium Trucks (F5 vehicles in the FHWA classification scheme) and Heavy Trucks (F6-F13).

The new models were incorporated into the framework of the Baltimore Region Travel Demand Model and the TP+/VIPER software. The Baltimore Region Travel Demand Model is the traditional four step model maintained by BMC staff for air quality conformity analysis, corridor studies, and long range planning. The new process for modeling accounted for areas of heavy trucking activity, land use, truck prohibitions, and truck passenger car equivalencies (PCEs). In areas of heavy trucking activity, e.g., port facilities, land fills, etc., a total of 127 truck special generator zones were identified. The model results showed significant improvement over the previous model and compared well to traffic count data.

This presentation describes the process of developing a truck model using “adaptable assignment,” presents model results, and discusses the benefits of this approach over traditional methods.

Increasing truck traffic is becoming a major issue facing planners in many areas and the issue is only expected to grow in the future. The Federal Highway Administration’s (FHWA) freight analysis framework forecasts that freight tonnage and truck VMT will double in the next twenty years. Traditionally, truck modeling has received very few resources due to the

perceived high cost and low benefit of developing truck models. The traditional approach to creating a truck model has been to conduct a survey on truck movements to use to develop a model of truck trip rates, distribution patterns, and routes. This approach is generally too costly, however, due to the difficulty and high expense inherent in conducting a statistically valid truck survey. Consequently, the truck components of regional travel demand models have generally not been updated regularly. This has generally not been considered to be a problem; however, since truck traffic has been viewed as comprising a very low percentage of overall traffic. With truck traffic routinely now accounting for over 10% of all traffic on major roadways and using an even larger share of available road capacity, planners can no longer ignore the need to more accurately model truck traffic. The increased need for precision in air quality conformity modeling has also created a similar need. As a result, to meet these needs, an innovative, faster, less costly approach to developing a truck model has been developed using an approach called “adaptable assignment.”

Adaptable assignment is a practical method of working backwards from count data to develop a model. This approach was used to develop new truck models for the Baltimore Metropolitan Council (BMC). The BMC maintains the regional travel demand model used for regional modeling for the Baltimore Region as shown in Figure 1. The BMC model is a traditional 4-step model within the framework of the TP+/VIPER software. Truck models were developed for two trip purposes: medium trucks and heavy trucks. Medium trucks were defined as vehicles with 2 axles and 6 tires (F5 in the FHWA classification scheme) and heavy trucks were defined as vehicles with 3+ axles (F4 and F6-F13) as shown in Figure 2. Detailed classification count data was available at over 600 locations throughout the BMC modeled network for the model’s base year of 2000. Medium and heavy truck trip tables were synthesized from this count data for comparison with model truck trip tables.

The existing BMC truck models were developed in 1964-65 from survey data collected during the Baltimore Region Transportation Study of 1959-62. A review of these models found them to be unsuitable as a starting point. As a result, the Phoenix Truck Model from the FHWA Quick Freight Response Manual was chosen as a starting point. Adjustments to the Phoenix model were made using parameters from other urban areas to create initial models. This initial trip tables were modified by the adaptable assignment process, to produce new tables whose assignment much more closely matched the classified count data. The new models were based on retail, industrial, and office employment and households. The resulting trip table was systematically compared to the initial table to understand the differences. Several improvements to the initial models were then made to better reflect those differences:

1. Truck Special Generators
2. Truck Prohibitions
3. Truck Passenger Car Equivalents
4. Sensitivity for Land Use
5. Sensitivity for Jurisdiction
6. Improved method for estimating External Truck Trips

Figure 1: Map of Baltimore Region

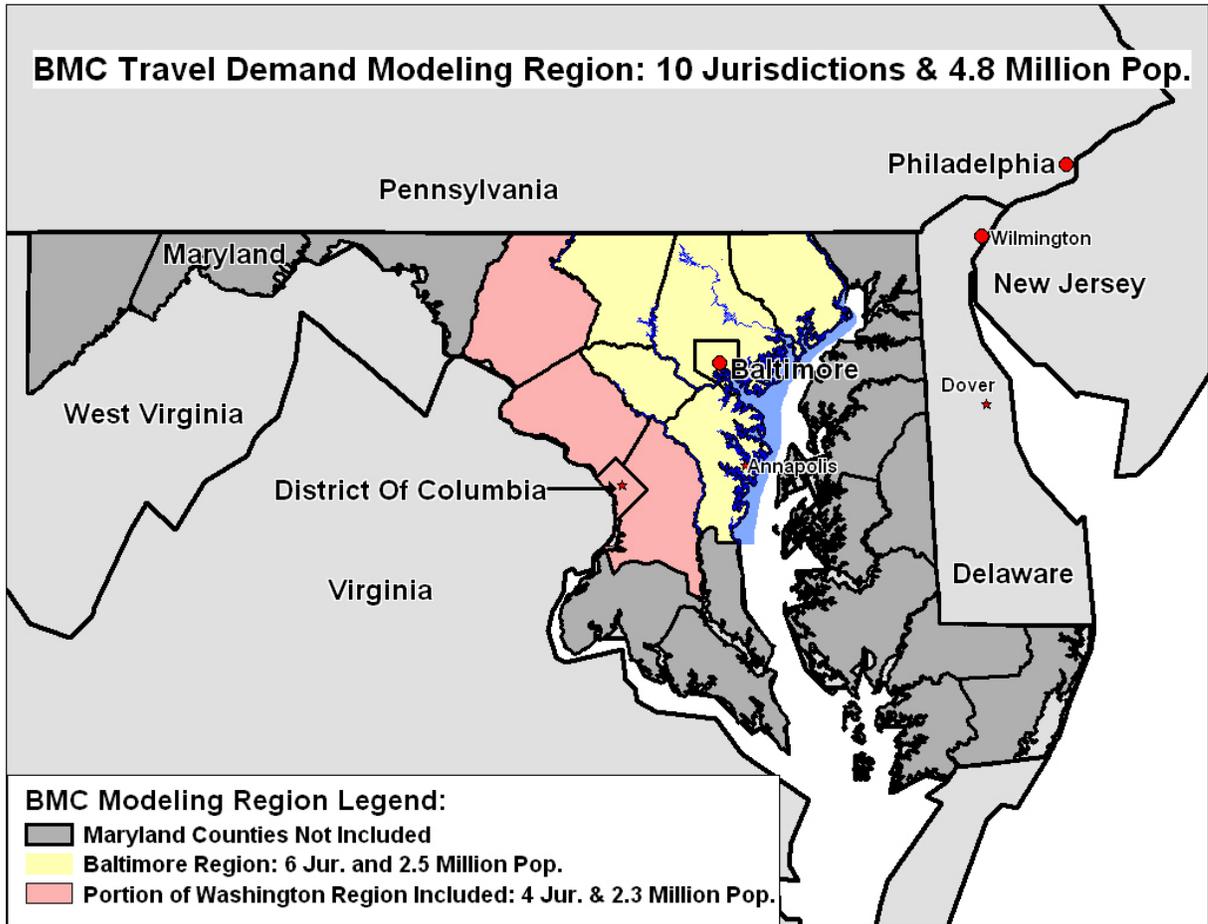


Figure 2: Truck Definitions

Heavy Truck: 3+ Axles



Medium Trucks: 2 Axles and 6 Tires (Box/Panel Trucks)



The truck special generators were added to address the problem of under simulation in areas of high truck activity. A total of 127 Transportation Analysis Zones (TAZs) were selected from the modeling region's 1,463 TAZs. The selection process was based on input from both Modeling/Technical and Freight/Policy staff and committees. This partnership proved invaluable to identifying potential truck special generators as it took advantage of the experience and expertise of both types of staff and committees. The truck special generator zones were categorized according to six different types and two different scales as shown in Table 1. Business district covered the CBD areas of cities and large suburban town centers and malls. Warehouse/Manufacturing were generally industrial parks and large warehouse areas associated with trucking. Intermodal/Transfer accounted for facilities where goods moved to/from truck including port terminals. Airport accounted for public airports with significant truck activity. Baltimore-Washington International Airport was the only such airport in the BMC model. Institutional/Other was a miscellaneous category to account for quarries and landfills which had significant trucking activity. Delivery/Medium Truck was used for zones with high levels of medium truck activity, e.g., FedEx facility, but little heavy truck activity. The two scales of large and small were used to indicate size. A threshold of 300 trucks per day was used to separate large from small zones for every category other than business district.

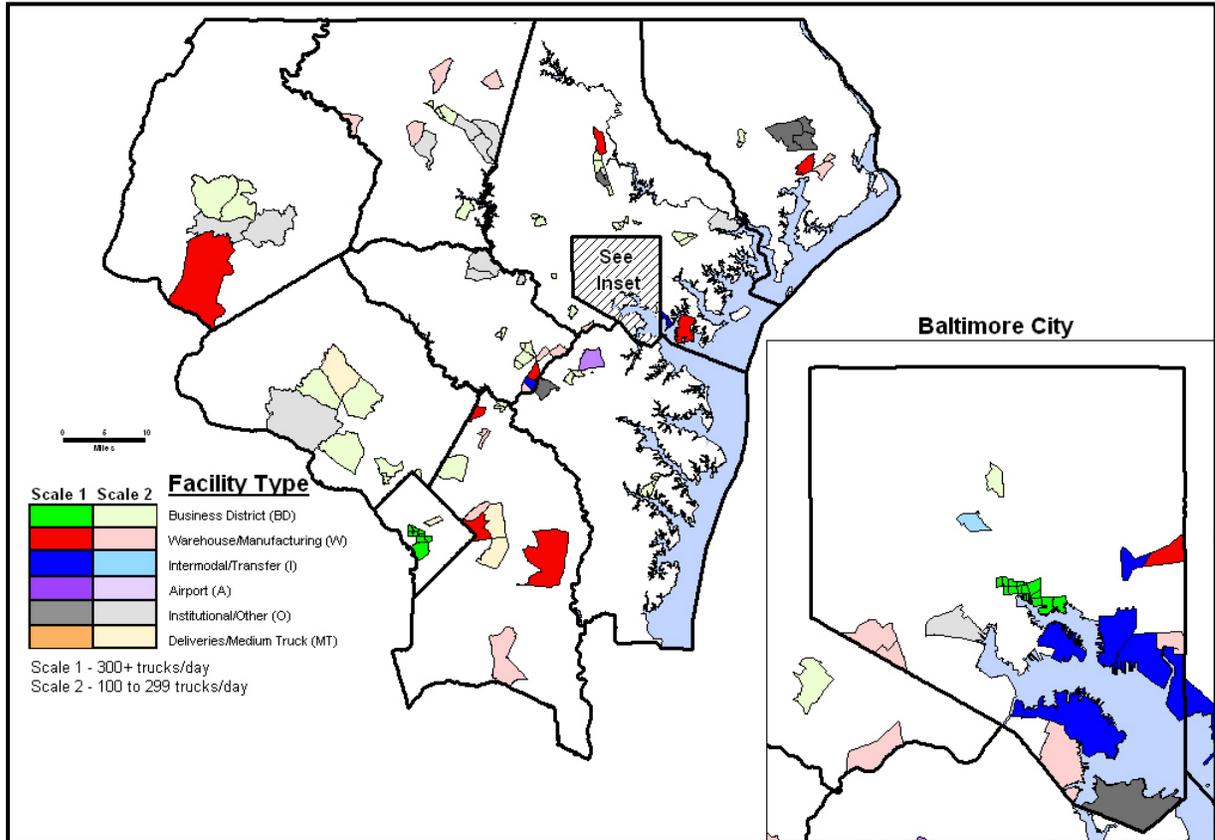
Table 1: Description of Truck Zone Categories

Truck TAZ Type	Scale (Trucks/Day)	
	Large	Small
Business District (BD): central business districts, major retail areas/large malls, colleges	Baltimore DC	Annapolis Columbia Towson
Warehouse/Manufacturing (W): warehouse, manufacturing, & processing facilities, industrial parks	300+	100-299
Intermodal/Transfer (I): facilities where freight transfers from truck to another mode	300+	100-299
Airport (A):	300+	100-299
Institutional/Other (O): quarries, landfills	300+	100-299
Delivery/Medium Truck (MT): facilities that process mail or primarily generate medium truck activity	300+	100-299

Figure 3 shows a map of the truck special generator zones. Although there was a concentration of truck zones in the Baltimore and Washington CBDs and around the Port of Baltimore, many of the zones were dispersed along freeways and major highways in outlying areas.

Truck prohibitions were placed on roadways with daily prohibitions only. Passenger car equivalencies (PCE) were added to better account for the extra capacity trucks use. After considerable research of potential PCEs, a decision was made to use the PCEs from the 2000 Highway Capacity Manual of one heavy truck equals 2.0 cars and one medium truck equals 1.5 cars. Sensitivity to the BMC model's 4 land use density codes: CBD, Urban, Suburban, and Rural and for each of the model's 10 jurisdictions was also added.

Figure 3: Map of Truck Special Generators

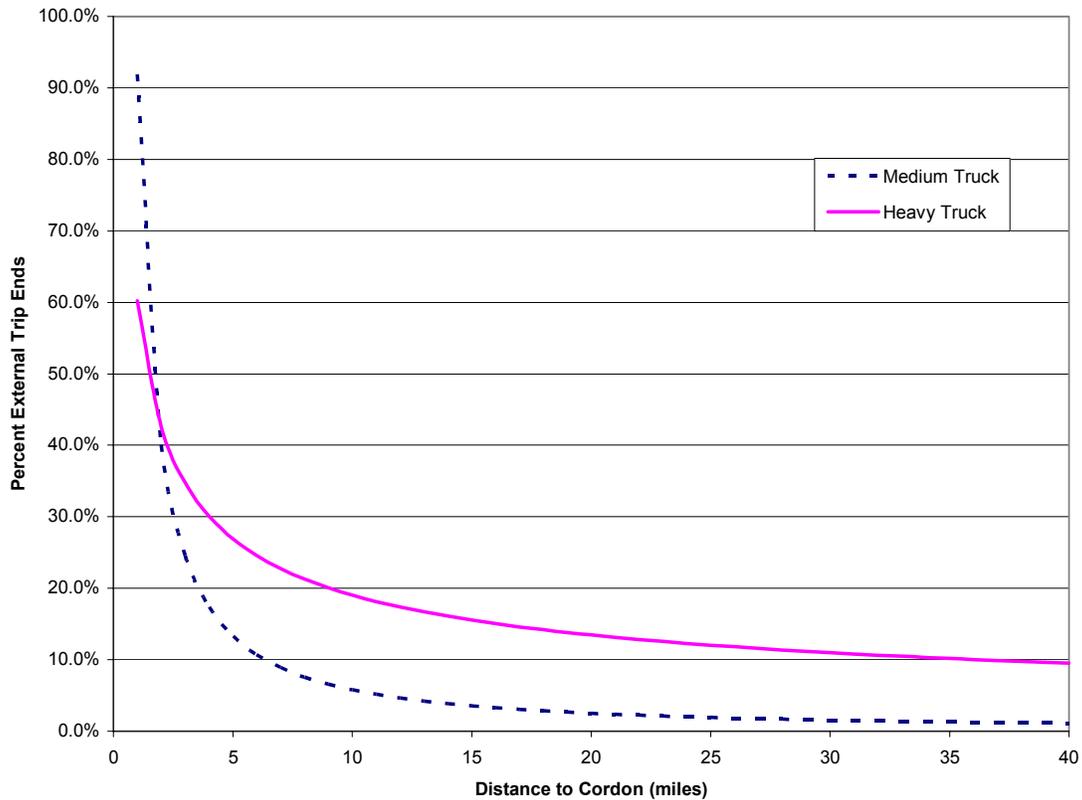


Lastly, an improved method of estimating external trips was developed. The old BMC model had grouped all external trips together for each of the model's 42 external stations. The new method separates external station trips into 4 categories: personal use automobiles, heavy trucks, medium trucks, and commercial vehicles. The external trip model assumes that the generation model estimates total trip ends. The external share of the total trip ends is modeled as a function of the zone's distance to the model's cordon, along the highway network. The external share model is shown in Figure 4, the equation of which is: Percent External (HT) = $0.602 * D^{-0.5}$ and Percent External (MT) = $0.919 * D^{-1.2}$ where D is the distance to the nearest external station in miles. The external trip ends at the internal zones are balanced to match the total external trip ends at the external stations. Thus, the cordon volumes are preserved. At the external stations, both Heavy and Medium truck trips were split into external vs. through (X/X), based on 2000 total weekday volumes posted on the network and a total X/X trip table provided by BMC. First, the percentage of total X/X trips by station was determined, using a look-up table to estimate the external trip share (= 100% - through trip share) for each station.

For X/X trip patterns, external stations where X/X Heavy and Medium truck trips should be expected were examined. By making assumptions about likely X/X patterns, an "X/X pattern file" was developed. This was used to create a seed matrix, which was then Fratared to match the estimated number of daily X/X Heavy and Medium truck trip ends at each station. The

final X/X 2000 daily total for Heavy Truck is 7,730 and for Medium Truck is 1,831. These volumes are not significant in the context of the entire model, but are important for analyses that focus on the major regional roadways.

Figure 4: Truck External Share Model



Once the improvements to the initial truck models were complete, medium and heavy truck trip tables were estimated from the new models and compared to the observed truck trip tables developed from the counts. The adaptable assignment process was then used to systematically adjust the coefficients of the new truck models to better match the observed trip tables derived from the counts in an iterative process. Ten iterations of adaptable assignment were used for both the medium and heavy truck models. A calibration adjustment table called the delta table was developed to account for differences between the observed and estimated trip tables. Ideally, the delta table should be as small as possible. Tests were performed to ensure that no variables or other changes could be made to better account for the differences between the observed and estimated tables. The final new medium and heavy truck models are shown in table 2.

Table 2: Final Medium and Heavy Truck Models

$$MT = 0.70 * (0.178 * INDEMP + 0.177 * RETEMP + 0.048 * OFFEMP + 0.069 * HH)$$

$$HT = 0.90 * (0.199 * INDEMP + 0.141 * RETEMP + 0.029 * OFFEMP + 0.068 * HH)$$

Special Generator TAZ Factors:

Type	Scale		Small	
	Large	HT	MT	HT
Business District	1.3	1.1	1.2	1.3
Warehouse/Mfgr.	1.0	1.9	1.0	1.8
Intermodal Transfer	1.0	3.8	1.0	3.0
Airport	1.0	1.0	1.0	1.0
Institutional/Other	1.0	2.7	1.0	1.4
Delivery/Medium Truck	1.3	2.0	1.0	1.6

Factor for density code:

Type	MT	HT
Rural	1.4	0.8
Suburban	0.9	0.9
Urban	0.8	1.0
City Center	0.8	0.5

Factor for jurisdiction:

Type	MT	HT
Baltimore City	1.1	1.2
Anne Arundel	1.2	1.2
Baltimore County	1.3	1.2
Carroll	1.3	1.1
Harford	1.5	1.7
Howard	1.2	1.2
D.C.	0.7	0.4
Montgomery	1.0	0.7
Prince George's	1.2	1.0
Frederick	0.6	0.6

The new truck models produced very different results from the old truck models as shown in Table 3. The new models had 71% fewer medium trucks and 133% more heavy trucks. Medium trucks declined dramatically for two reasons. First, the old medium truck model included some two axle 4 tire trucks which are now classified as commercial vehicles, a trip purpose which did not exist in the old model. Second, the old medium truck model, which was based on population and retail employment, had a much higher coefficient on population than retail employment. As a result, medium trucks were being vastly over simulated and concentrated in residential areas. In contrast, the new medium truck model has a lower coefficient on households relative to employment. The new models also showed much greater future growth in truck traffic. Additionally, the accuracy of the new models was greatly superior to the old models as measured by the percent RMS error. The new models

had percent RMS errors of 27% for heavy trucks and 24% for medium trucks. The improved assignment for the truck and commercial vehicle purposes contributed toward improving the overall assignment for all vehicles and for personal cars. The assignment for personal cars improved because of the improvements in external station modeling and the elimination of the medium truck over simulation problem in residential areas. Lastly, the new truck models much more closely matched the count volumes by facility type.

Table 3: Differences between New versus Old Truck Models

Measure	Heavy Truck	Medium Truck	Commercial Vehicle	Personal Car	All Vehicles
2000 Vehicle Trip %					
Old	0.9%	7.2%	N/A	91.9%	100.0%
New	2.1%	2.1%	7.0%	88.8%	100.0%
% Growth: 2000-2025					
Old	25.7%	19.6%	N/A	22.0%	21.9%
New	41.1%	22.1%	33.3%	22.6%	23.8%
% RMSE					
Old	394%	138%	N/A	45%	43%
New	27%	24%	13%	36%	34%

Facility Type	Heavy Truck Traffic Percentages			Medium Truck Traffic Percentages		
	Count	New Model	Old Model	Count	New Model	Old Model
Freeway	6.8	7.1	2.4	3.1	2.9	11.4
Arterials	3.9	4.0	1.2	2.6	2.5	8.2
Collectors	4.7	5.1	0.9	3.0	3.0	7.5
All Roads	5.8	6.0	2.0	2.9	2.7	10.6

Table 4 compares the adaptable assignment method for developing a truck model to the traditional survey based approach using the BMC model. The adaptable assignment method cost far less and took much less time than the traditional survey based approach. The first primary work activity involved with adaptable assignment is in obtaining and organizing reliable count data. BMC staff spent several months organizing classified count data, checking for consistency, and linking it to the model network. The second primary work activity was selecting truck special generator TAZs. BMC staff worked with Freight committees and officials over a period of several months and made several site visits to develop a final list of truck TAZ locations. The primary work activity involved with the traditional approach is in designing, conducting, and analyzing truck survey results. A truck survey is a major undertaking because of the difficulty in obtaining reliable survey data from trucking firms.

The primary data obstacles with the adaptable assignment approach are twofold. First, is the issue of maintaining consistency in count data. In the BMC application, there were many inconsistencies between local and state of Maryland count data that could not be resolved and resulted in local counts being discarded. A second issue was the lack of observed average trip length data to compare to model results. The adaptable assignment approach generally results in average trip length being shortened. The average trip length in both the new heavy and medium truck models was less than it had been in the old truck models, but in the absence of observed survey data, there was no way to verify whether or not this was correct. With the traditional survey based approach, the key data obstacle is in obtaining adequate truck survey results. The BMC in conjunction with the Metropolitan Washington Council of Governments conducted an Internal and External Truck Survey in 1995-1996. The survey was unsuccessful because of an extremely low response rate from trucking firms due to privacy concerns. As a result, there was inadequate data from which to calibrate a model. The second problem with the traditional approach is the lack of data at external stations. It is generally cost prohibitive to survey every external station in a modeling region. The BMC model has 42 external stations, but the cost of surveying them all is prohibitive. As a result, only a subset of the most major roadways can be surveyed which results in no data being available for the remaining locations.

Table 4: Adaptable Assignment versus Traditional Survey Based Approach

Criteria	Adaptable Assignment	Traditional Survey Based Approach
Cost	\$42,500	\$500,000-\$1,000,000 Est. \$325,000 in 1995-1996
Time	1 year	2-3 year Est.
Primary Work Activity	Obtaining/Organizing reliable count data Selecting truck special generators	Truck Survey
Data Obstacles	Maintaining consistency in Local/State count data No average truck trip length to compare model results to	Obtaining adequate truck survey results for model development Inadequate survey data at External Stations

In conclusion, the adaptable assignment approach was much faster, cheaper, and better than the traditional survey based approach. The adaptable assignment approach also showed significant improvement over the old model in accuracy and logic. The project also underscored the importance of including both technical and policy staff and committees in the model development process. The expertise and input that both sides offered was critical to the success of the project.

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Modeling Commercial Vehicle Travel

William G. Allen, Jr., P.E, *Transportation Consultant* and Paul Agnello, *Baltimore Metropolitan Council*

Abstract. A new Commercial vehicle trip forecasting model has been developed for the Baltimore Metropolitan Council (BMC). BMC has included trucks in its regional modelling for many years. However, it has not specifically included a fairly important category of non-personal travel that uses passenger cars, light trucks, and other vehicles not included in the “Truck” model. These trips include light-duty delivery vehicles, taxis, government vehicles, service personnel, craftsmen, tradesmen, and similar vehicles. BMC recently revised its Medium and Heavy Truck trip models. In conjunction with this effort, a completely new Commercial vehicle trip model was also developed.

The principal challenge in estimating Commercial vehicle trips is to define them and obtain any kind of data on observed trip patterns. Traditional surveys were judged unlikely to be useful, so the project researchers devised an innovative way to estimate Commercial vehicle counts at those locations where Maryland DOT classification count data already existed.

BMC staff conducted new manual counts at a representative sample of locations throughout the region. Commercial vehicles were defined as those bearing text, a logo, or carrying equipment of an obvious commercial nature. A database was created with various link characteristics. The consultant used this database to calibrate a “count model”, which was then applied to estimate daily Commercial counts at the 550+ classification count locations for the year 2000. These counts indicated that Commercial traffic (excluding Medium and Heavy Trucks) is almost 8% of the total daily volume.

BMC retained a consultant who has refined the practical application of a methodology to synthesize a trip table from count data. Working “backwards” from the count data, the consultant not only created such a trip table, but then used it to develop a Commercial vehicle trip forecasting model that would produce link-level volumes with reasonable accuracy.

A Commercial vehicle trip model from another region was adapted as a starting point. The consultant then applied a procedure called “adaptable assignment” to systematically adjust this interim model so as to better match the counts. This process resulted in a number of changes to the interim model and also produced a calibration adjustment table. This adjustment table is then multiplied by the nominal output of the model, producing a new table whose assignment comes much closer to matching the count data. The resulting assignment error is -1.9% and the regional percent root-mean-square error is 13%, both of which are excellent results.

The result is a process that both exhibits reasonable sensitivities to the key input variables (employment by type and households) and has been shown to match the synthesized counts to a fairly high degree of accuracy. A 2025 forecast was made with this new process and the results found to be reasonable. The entire procedure has been implemented within the framework of BMC’s regional model set, using the TP+/Viper software package.

A new Commercial trip forecasting model has been developed for the Baltimore Metropolitan Council (BMC). BMC has included trucks in its regional modeling for many years. However, it has not included an important category of non-personal travel using passenger cars, light trucks, and other vehicles not included in the “Truck” model. These trips include light-duty delivery vehicles, taxis, government vehicles, service personnel, craftsmen, tradesmen, and similar vehicles. BMC recently revised its Medium and Heavy Truck trip models. As part of that project, a new Commercial vehicle trip model was also developed.

In this model, “Commercial” refers to those trips that are business-oriented and are not personal transportation, but do not involve a Medium or Heavy Truck. This includes a wide range of vehicles: pickups, vans, minivans, and sport-utility vehicles (SUVs), and passenger cars used for business purposes. Light trucks, vans, and SUVs used for personal transportation are not included.

This is a new category of trip that has not been commonly recognized in regional travel demand models but which is becoming the focus of attention in several urban areas. It includes package delivery vehicles, postal vehicles, couriers, equipment repair and service technicians, craftsmen (carpenters, plumbers, etc.), government workers, taxis, and many other types of light-duty vehicles. Planners are beginning to realize that business-related travel is very poorly identified in home-interview surveys. The difficulty in identifying the travel patterns of such trips has doubtless kept many planners from including them in the modelling process. In some other urban areas, the Commercial category includes Medium Trucks, making this an even more important group. Since the BMC model already estimates Medium Trucks separately, Commercial trips are defined differently than elsewhere.

Observation of the traffic stream on any roadway will reveal that Commercial trips represent a category of travel that is too large to ignore. Exclusion of these trips will result in either underestimating traffic volumes, or (perhaps worse) implicitly incorporating their volume within some other category, most likely non-home-based travel. Since Commercial trips obviously have different travel characteristics than most personal travel, accounting for these trips in a separate category will improve the accuracy of the model.

Since much of this category consists of delivery people and others who spend much of their workday either outdoors or in their vehicle, capturing their travel pattern data is a particular challenge. A workplace survey might identify some of these trips, but the authors believe that a comprehensive Commercial trip survey is probably not feasible. Thus, an alternative method has been developed to estimate the model parameters.

This method relies on a procedure that works “backwards” to develop a trip table from count data. There are many such procedures available; the consultant author has developed a relatively simple one called “adaptable assignment”. This procedure assigns a starting trip table, systematically compares the resulting assigned link volumes to the counts, and adjusts the trips so as to produce a closer match between assigned volumes and counts. The starting trip table is usually based on a model borrowed from another urban area. Adaptable

assignment produces a set of trip table adjustments. Examination of these adjustments can identify areas in which the starting model can be improved and the process re-applied.

The Commercial model developed in this study consists of a trip generation and distribution model, external and X/X table procedures, and a calibration adjustment table that is carried into the forecasting phase.

The basic methodology of this study relies on developing a trip table from counts. However, counts of Commercial traffic are not commonly available. Worse, obtaining such counts is complicated by the difficulty in defining Commercial vehicles in a manner that is suitable for traffic counting. The consultant author developed a procedure that leverages the relatively large database of classification counts conducted by the Maryland Department of Transportation (MDOT). These counts identify volumes stratified by the 13 FHWA categories based on the size and type of vehicle. These counts were available at approximately 550 locations throughout the BMC modelled area for 2000.

The BMC author conducted new counts of Commercial traffic at 113 of those locations. For these counts, “Commercial” was defined as any vehicle that displays text, logo, or trademark, or that is transporting equipment of an obviously commercial nature. This definition was coordinated with the FHWA category descriptions so as to avoid duplication with the BMC Medium and Heavy Truck categories.

The counts were conducted in early 2002, at a variety of locations around the BMC modelled area. BMC staff obtained a sample of links stratified by functional class group and area type. Counts were conducted for 30 minutes at a time, between 10 AM and 3 PM. Test counts indicated that 30 minutes’ worth of this kind of data should be sufficiently representative of a typical weekday’s activity. In addition, a total vehicle count was made at the same time. This permits the calculation of a “percent Commercial” value for each link. Additional data were assembled from the MDOT classification data and the coded network, including daily counts for vehicle types F1 – F13, jurisdiction, speed class, capacity class, functional type, area type, number of lanes, weekday count, and directionality.

These data were used to develop a model of the percent Commercial traffic. For each observation, the dependent variable is the percent Commercial traffic and the independent variables are as described above. Such a model could be applied to the approximately 550 classification count links, producing a count database that could be used in the adaptable assignment process.

Since the dependent variable is a fraction (0.0 to 1.0), the logit structure was selected. This function is $p = 1/(1+e^U)$, where p is the percent Commercial and U is the “utility” of Commercial traffic, expressed as a linear function of the independent variables, plus a constant term (“bias coefficient”), which varies by jurisdiction and facility type and area type. Although logit models are most commonly developed using discrete choice data, it is possible to estimate coefficients using aggregate data such as in this case.

The best model had a 25% RMSE, 0.43 r^2 , 0.59 ρ^2 with respect to zero, and 0% total error. Table 1 shows the model.

According to the utility equation in Table 1, the percent Commercial increases as the capacity class decreases, the speed class increases, the number of lanes increases, the percent bus increases, the daily F1 or F11 count decreases, and the daily F7 or F12 count increases. The city center has a higher Commercial share, while Rural and Suburban areas have lower shares. Freeways have a slightly lower share than other roadways. It makes sense that Commercial traffic is higher on downtown arterial and collector streets, since much of this traffic is probably relatively short trips between business establishments. The synthesized Commercial count is simply the Commercial share times the weekday total count.

Table 1 - Commercial Count Model

$$\text{Percent Commercial} = 1/(1 + e^U)$$

$$U = c_{Jur} + c_{FD} + 0.0042 * CAPCLASS - 0.0058 * SPDCLASS - 0.0111 * LANES - 0.0472 * p_{Bus} + 0.0004 * F1 - 0.00015 * F7 + 0.0005 * F11 - 0.0005 * F12$$

where:

CAPCLASS = network capacity class

SPDCLASS = network speed class

LANES = number of lanes (each way)

pBus = percent of traffic count that is buses

F1 = classification count (motorcycle), both directions

F7 = classification count (4 axle, single unit truck), both directions

F11 = classification count (5 axle, multiple unit truck), both directions

F12 = classification count (6 axle, multiple unit truck), both directions

cJur = bias coefficient by jurisdiction

Baltimore City -0.32

Anne Arundel -0.02

Co

Baltimore Co 0.15

Carroll Co 0.06

Harford Co -0.06

Howard Co -0.01

Washington 0.00

area

cFD = bias coefficient by facility group and area type

Facility Group	Rural	Suburba n	Urban	City Ctr.
Freeway	2.62	2.62	2.68	2.30
Arterial	2.52	2.62	2.68	2.43
Collector	2.41	2.65	2.71	2.19

The starting generation model was borrowed from the Lehigh Valley in Pennsylvania. For distribution, the new BMC Medium Truck distribution model's F factors were used. The starting model also accounts for zones in which there is strong reason to believe that the Commercial trip activity is higher than the standard trip rates would indicate. The most important zones are few enough in number that they can be identified individually and classified in a way that allows the starting model to account for them. Although no data are available to specifically determine the increase in Commercial trips for such areas, a reasonable estimate can be made and confirmed in the adaptable assignment process.

Six types of zones have been identified and within these types, the zones are further divided as to their relative scale: smaller vs. larger. The BMC author determined that the level of 300 truck trips per day would be used to distinguish smaller from larger facilities. Although these classifications are rather simplistic, the authors believe that this is a reasonable trade-off against the need to maintain and forecast this data item. The truck zone types are defined below:

- Business District: core area of central business districts, major retail areas, college campuses
- Warehouse/Manufacturing: manufacturing and processing facilities, industrial parks
- Intermodal Transfer: facilities where freight transfers between trucks and another mode – mainly the port areas
- Airport: Baltimore-Washington International (BWI -- a special category)
- Institutional/Other: landfills, quarries
- Delivery/Medium Truck: facilities that process mail or express delivery packages

The external trip model assumes that the generation model estimates total trip ends. The external share of the total trip ends is modelled as a function of the zone's distance to the model's cordon, along the highway network. The external share model is shown in Figure 1, the equation of which is: Percent External = $0.468 * D^{-1.2}$, where D is the distance to the nearest external station in miles. The external trip ends at the internal zones are balanced to match the total external trip ends at the external stations. Thus, the cordon volumes are preserved.

At the external stations, Commercial trips were split into external vs. through (X/X), based on 2000 total weekday volumes posted on the network and a total X/X trip table provided by BMC. First, the percentage of total X/X trips by station was determined, using a look-up table to estimate the external trip share (= 100% - through trip share) for each station.

Due to the different sizes of network and modelled area, and other differences, it is not feasible to transfer the Lehigh Valley Commercial distribution model. However, Commercial trips should be similar enough to Medium Truck trips that it should be feasible to use the BMC Medium Truck F factors. The Medium Truck model uses a gamma function to define its F factors, as follows:

$$F = \alpha * t^{\beta} * e^{(\gamma t)}$$

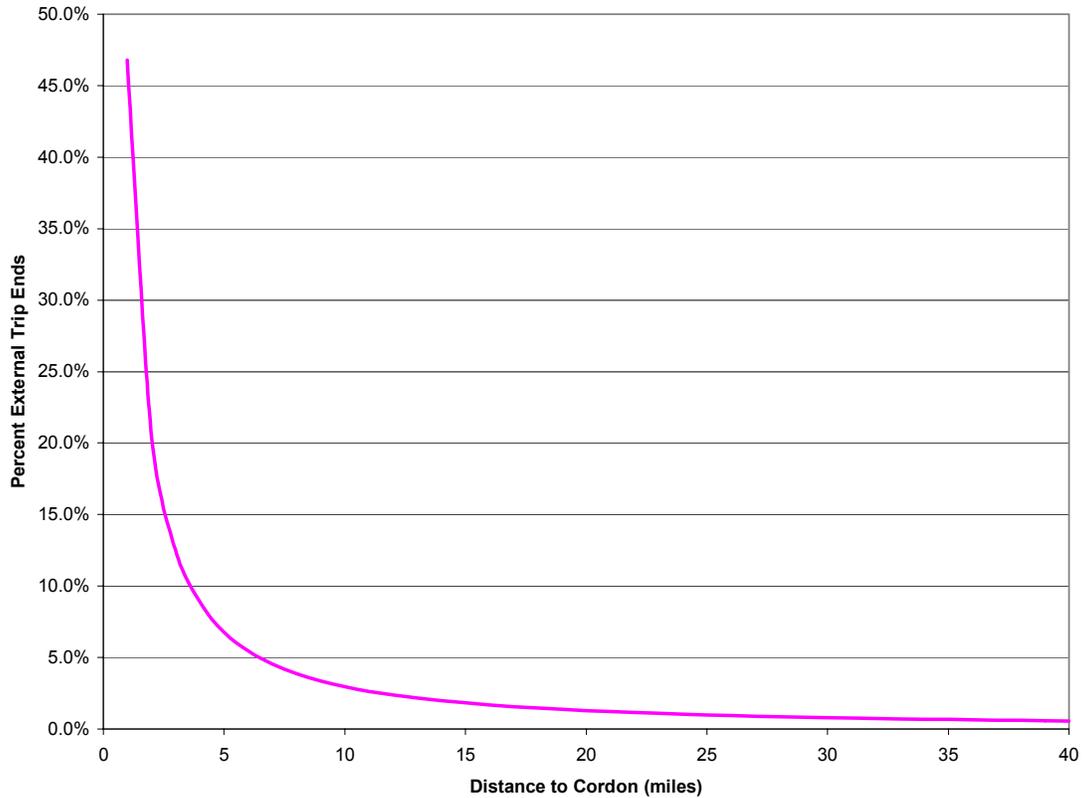
where:

t = travel time, minutes

α, β, γ = calibrated coefficients

The Medium Truck coefficients of e^{14} for α , -2.95 for β , and 0.0 for γ were used. (The gamma value of zero effectively converts this into an exponential model.) The same F factors were applied to I/I and external trips. Figure 2 shows the resulting F factor curve. The starting model's estimated trip length is 16.2 min, which seemed reasonable.

Figure 1 - External Share Model

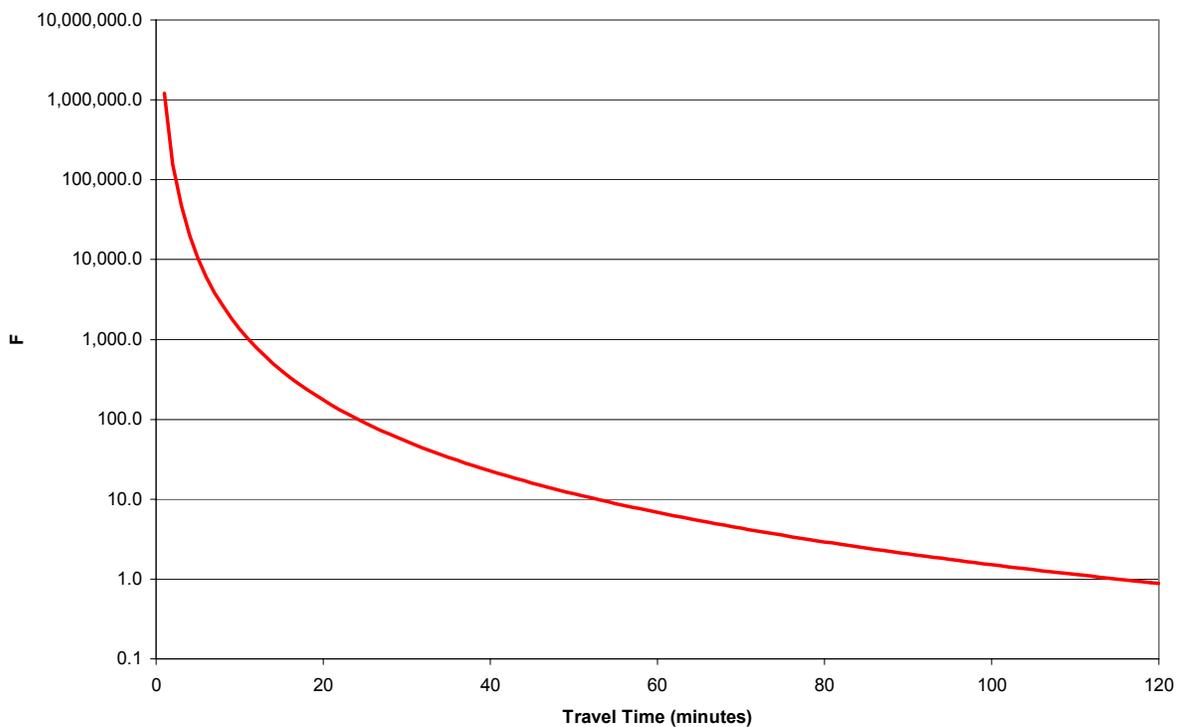


For X/X trip patterns, the consulting author examined the external stations where X/X Commercial trips should be expected. By making assumptions about likely X/X patterns, the consultant developed an “X/X pattern file”. This was used to create a seed matrix, which was then Fratared to match the estimated number of daily X/X Commercial trip ends at each station. The final X/X 2000 daily Commercial total is 4,229. This volume is not significant in the context of the entire model, but it is more important for analyses that focus on the major through roadways in the region.

This model was applied to year 2000 conditions. The total error was +8.7% and the percent root-mean-square error (%RMSE) was 70%. These figures represent a worse-than-average degree of accuracy and it was clear that this could be improved upon. The resulting trip tables were used as the starting point for the adaptable assignment process.

The nature of the adaptable assignment process requires that it is iterated several times until a balance has been achieved and little additional assignment accuracy can be expected. The best results were achieved by using 10 iterations. The new trip table is Frateded after the 5th and 10th iterations, so that the external station totals will match the counts. Links in the Baltimore region are given a higher priority than Washington area links, so as to try to match those counts more closely. The adaptable assignment process produces a new trip table. The ratio of this table to the starting trip table is called the “delta table”. This table is an O/D matrix of calibration adjustments that, when multiplied by the starting trip table, produces a table that matches

Figure 2 - Commercial F Factors



the counts fairly closely. The trip ends of the final-minus-starting table were compared to the land use data to see if there were any systematic employment- or household-based adjustments that would improve the model. None was found. Next, the consulting author cross-tabulated the delta trip ends and the starting model trip ends by various factors, including truck zone type, jurisdiction, and density code. This analysis indicated a number of modifications to the truck zone factors, as well as a need for jurisdiction- and density code-based adjustment factors.

After several iterations of this analysis, several adjustments were developed for the starting generation model. The revised model is shown in Table 3. This version incorporates adjustments based on the area type and jurisdiction of the zone. These adjustments reduce

the number of trips in the city center. Since those areas have many more employees, it would make sense that the Commercial trip rate per employee might be less there. The final truck zone factors suggest that only in the larger Business District and Delivery/Medium Truck zones are the Commercial trips per employee higher than elsewhere. In both those cases, the factors for the “Larger” zones exceed those for the “Smaller” zones, which is logical.

The revised interim model estimates 1,124,000 total Commercial trips (1,038,000 I/I, 82,000 external, 4,000 X/X). Although adaptable assignment identified a number of changes that make the starting model more accurate, the resulting accuracy is still not as good as one would like. As described above, adaptable assignment can be used to “inform” a model, presumably making it more accurate. This should make the adjustment factors smaller, but they will never be zero.

Table 3 - Final Generation Model

$$\text{COM} = 0.80 * (0.454 * \text{INDEMP} + 0.501 * \text{RETEMP} + 0.454 * \text{OFFEMP} + 0.146 * \text{HH})$$

Factor for truck zone type:

Type	Larger	Smaller
Business District	1.2	1.0
Warehouse/Mfgr.	1.0	1.0
Intermodal Transfer	1.0	1.0
Airport	1.0	N/A
Institutional/Other	1.0	1.0
Delivery/Medium Truck	3.0	2.5

Factor for area type:

Rural	0.8
Suburban	1.0
Urban	1.5
City Center	0.7

Factor for jurisdiction:

Baltimore City	1.0
Anne Arundel	1.5
Baltimore County	1.2
Carroll	1.7
Harford	2.1
Howard	1.2
D.C.	0.5
Montgomery	0.7
Prince George’s	1.2
Frederick	0.6

This adjustment table then becomes an integral part of the model. It is always multiplied by the model output, to become the “final” trip table for assignment. From experience in other studies, the consulting author believes that this method of highway assignment calibration is superior to other techniques and produces results that are not only more accurate in the base year, but more credible in the forecast years.

The final “difference” table (final minus starting) totals 55,077 trips. The most desirable characteristic of a delta trip table is that it is small, relative to the starting table. The total delta is 5% of the starting trip table, which is very acceptable. The relative delta should also be consistent across the region. In this case, the relative delta is a little high in Baltimore City and Carroll County. No explanation could be found for this.

An interesting characteristic of this process is that the new trip table has a shorter average trip length than the original table. Mechanically, this is because adaptable assignment factors the starting trips to match the counts, and the majority of the trips from any zone tend to go to nearby zones. Thus, the process tends to magnify these close trips. However, this may make some rational sense, since very short trips tend to be undercounted in trip surveys. Here, including the delta table reduced the average trip length from 15.4 mi. to 14.3. Since the original value was not calibrated to any observed data, this is of no great concern.

As the final step in the development of this model, the table from the revised starting model was multiplied by the adjustment table and the resulting table was assigned to the BMC 2000 network. This procedure used the new BMC Truck assignment procedure, so as to:

- 1) maintain Medium and Heavy Truck volumes separately by link,
- 2) prevent Medium and Heavy Trucks from using truck-prohibited links, and
- 3) factor Medium Truck volumes by 1.5 and Heavy Truck volumes by 2.0, for the purposes of the V/C calculation

The resulting assigned volumes were compared to the synthesized Commercial counts, producing the report shown in Table 4. The total error is -1.9%, while the %RMSE value is 13%. This is a *substantial* improvement over the starting model. BMC and the consultant considered these results acceptable.

There is little difference in the estimated/observed ratio, when stratified by the various fields shown in these reports. The %RMSE values tend to be better (lower) for the higher-type, higher-volume facilities, but this is to be expected.

The adaptable assignment process is at least as valid as the count data. The result of this process is a model that both matches the counts and displays reasonable sensitivity to changes. The new model’s coefficients and the inclusion of special factors for truck zones produces logical and defensible trip patterns.

Most other regional travel models do not specifically account for Commercial vehicle trips. In most cases, these trips are counted as Truck or NHB trips. Counting them as Truck trips is incorrect, since the trip patterns and average trip lengths are so different. Counting them as NHB is incorrect, since Commercial trips are not personal travel and are not subject to

changes in mode choice. Counting these trips in this new category of travel represents an improvement in accuracy and credibility, compared to the old model.

A model is not complete until it has been used to make a forecast. As the final step in the development of the Commercial model, it was used to forecast 2025 trips. The results are shown in Table 5. These figures reflect a fairly modest growth in Commercial travel to 2025. Most of this is due to an increase in total Commercial trips, while some is due to increased trip length. These estimates do not appear unreasonable.

Table 4 - Assignment Report

County	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT
External	90472	83633	0.92 0.19	84	27138	25089
BaltCity	133376	133739	1.00 0.13	111	34515	34767
AnnArndl	409880	399052	0.97 0.14	209	343244	336454
BaltmrCo	545202	543956	1.00 0.12	288	345769	340274
Carroll	39864	39421	0.99 0.05	70	42184	41832
Harford	132616	128452	0.97 0.16	144	175273	167454
Howard	226280	223248	0.99 0.09	110	176891	173480
Montgomery	114159	113015	0.99 0.12	38	112201	109490
PG	228631	222362	0.97 0.06	60	287201	277825
Frederick	27124	24287	0.90 0.16	22	71970	63656

Vol Class	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT
<= 999	260935	260205	1.00 0.23	539	185446	182292
1000-2499	542055	538528	0.99 0.12	341	349070	340215
2500-4999	613740	603638	0.98 0.08	173	603590	587671
5000-9999	530874	508794	0.96 0.08	83	478280	460143

Area Type	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT
Rural	656429	634338	0.97 0.16	539	752272	720063
Suburban	1171150	1155918	0.99 0.11	515	831522	817617
Urban	79314	80781	1.02 0.13	62	26578	26743
City Ctr	40711	40128	0.99 0.06	20	6014	5898

Roadway Type	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT
Freeway	1231181	1199476	0.97 0.08	339	1229499	1188380
>2 Ln Div	113233	115083	1.02 0.07	78	65425	65753
2WCLTL	31640	31517	1.00 0.03	28	21586	21390

Undivided	70628	72234	1.02	0.25	60	36622	37057
Arterial	210696	213030	1.01	0.14	175	61969	62671
Rural Hwy	65067	64819	1.00	0.07	101	69841	68883
Substndrd	84746	82936	0.98	0.25	188	73876	71864
Local	39728	40953	1.03	0.25	76	26370	26236
Ramp 1	2326	2647	1.14	0.15	2	744	834
Ramp 2	6455	3928	0.61	0.43	3	3001	1964
Ramp 5	1432	909	0.63	0.36	2	315	200
Cent Conn	90472	83633	0.92	0.19	84	27138	25089

Totals:

Count	1947604.000
Assigned Vol	1911165.000
Est/Obs Vol	0.981
RMS Error	52581053.000
Avg RMS Error	215.142
% RMS Error	0.125488
Links	1136.000
Obs. VMT	1616386.000
Est. VMT	1570321.000
Est/Obs VMT	0.972
Corr Coef R	0.996
Coef Var Rsq	0.992589

Table 5 - 2025 Forecast Summary

	2000	2025	% Change
Commercial Trips	1,179,800	1,545,600	31%
Avg. Trip Length	7.2	8.4	17%
Commercial VMT (000)	8,479.7	13,011.6	53%

Includes calibration adjustment.

The development of this model focused mainly on daily trips. Since the BMC model assigns trips by time period, time of day factors were needed to split the trips by period. Factors to accomplish this were obtained from the literature, as shown in Table 6.

Table 6 - Commercial Time of Day Factors

Period	Trip Share
Night (12 M – 6 AM)	4.5%
AM Peak (6 – 10)	25.1
Midday (10 AM – 3 PM)	28.9
PM Peak (3 – 7)	29.4
Evening (7 PM – 12 M)	12.1

The final Commercial trip model includes the following components:

- trip generation model (Table 3)
- trip distribution model (F factors as shown in Figure 2)
- procedure to calculate external trips (Figure 3)
- base year through trip table
- calibration adjustment factor table
- time of day splits (Table 6)

Florida Statewide Intermodal Highway Freight Model

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Florida Department of Transportation

Abstract. The Florida Statewide Intermodal Highway Freight Model is a commodity-based forecasting model that focuses primarily on long-distance freight movements surveyed as part of the U.S. Census Bureau's Commodity Flow Survey and Reebie Associate's TRANSEARCH database. While this focus on commodity transportation does not simulate local delivery or service trucks, these trucks are primarily regional in nature and are best modeled at the regional level. The focus on commodity freight addresses the large trucks moving on Florida's major highways, the shipment of commodities between regions in Florida and the shipment of freight between Florida and the rest of North America.

The Florida Statewide Intermodal Highway Freight Model meets several important needs: it provides forecasts of truck freight volumes for basic roadway design and maintenance purposes; it estimates truck volumes for proposed new roadways; and the model forecasts changes in truck volumes in response to changes in freight modal characteristics or in the Florida or national economy; and it provides the ability to analyze these policies based on changes in the input variables of the model. For modal operations the links on the network include time, distance, and cost information. The basic demand variables are population and employment. The model structure follows the basic framework of the four-step travel demand forecasting process. A mode split component is included to identify trucks to be assigned to the statewide highway model. This approach results in a model that is more easily understood by the ultimate users and ensures compatibility with existing models.

The model accommodates approximately 14 commodity groups. Appropriate employment and population variables were selected based on the U.S. Department of Commerce's Bureau of Economic Analysis 1996 Input-Output Tables. Those tables indicate the commodities used and produced by industry groups. Employment totals in those industries were used as independent variables for the production and attraction equations. The area covered by the model includes a detailed highway network of Florida and a sketch-level network for the rest of the U.S. The trip generation equations are developed through a linear regression of the TRANSEARCH data and the population and SIC employment on a county basis. The trip distribution step uses the standard gravity model in conjunction with friction factors from a deterrence function, $F=e^{-u}$. The coefficients, u , for the deterrence function were estimated for each commodity group to match the trip lengths from the TRANSEARCH freight database. The mode split model uses an incremental logit function which uses the base modal share as a starting point and then modifies the base share according to marginal changes in modal utilities. The assignment process is a one-iteration all-or-nothing equilibrium assignment. The loaded highway network from this model can be used as a preload to the passenger car models.

Overall highway evaluation measures indicate a high degree of correlation between observed and estimated traffic volumes as forecasted by the year 2000 Florida Statewide Intermodal Freight Model. The screenline summaries, volume-to-count ratios by facility type and area type, and root mean square error summaries all indicate that the model is a reliable tool for system-level freight/truck transportation planning analyses.

Modeling Of Freight Flow Assignment Through Intermodal Terminals

Jinghua Xu and Kathleen L. Hancock, *University of Massachusetts at Amherst*

Abstract. The paper develops an analytical model to assign freight across a highway and rail network through intermodal terminals. The proposed assignment procedure is the multi-modal multi-class assignment (MMA), a generalized cost assignment that allows trips assigned by individual modes or user classes to the network simultaneously. Specific operating characteristics of intermodal terminals are used to establish the intermodal transfer impedances. The different modes included in the research will be all highway, rail-highway, highway-rail, and highway-rail-highway. A key feature of the proposed approach is the evaluation of freight movements that transfer between rail and highway modes within a jurisdiction so that local planning agencies have a tool to measure activity at intermodal facilities as an overall part of the transportation infrastructure. The methodologies and algorithms are developed modularly and designed to be incorporated into any compatible modeling environment. A single case study, which focuses on a regional freight assignment across southern New England, is conducted using the model developed in this paper.

A Study of Getting Within, Going out, Coming into, and Through Truck Flows for the State of Mississippi Using Commodity Flow Survey Data

Haiyuan Wang, Yingjie Zhou, Yunlong Zhang, and Royce Bowden

Abstract. Some states such as Mississippi in spite of their relative small size have extensive intermodal freight transportation network that are composed of all major transportation modes. In this study, 1997 *Commodity Flow Survey (CFS)* database together with other freight related databases such as *Vehicle Inventory and Use Survey* and *Cargo Density Database* are used to describe freight flows coming into, going out, within and through the state of Mississippi. A methodology is used to break down the state level O&D data to the county level. The assignment results are combined from different O&D pairs to get the commodity tonnage on the network in the State of Mississippi. A methodology is developed to convert the freight flows to vehicle trips to facilitate model calibration and validation. The comparison between the truck volume determined by the conversion and the ground truck counts on the network shows a good consistency. The methodology developed can be applied to other states to model statewide freight transportation planning by utilizing the public domain *Commodity Flow Survey* database.

Coordinating Trip Data between Travel Demand and Operational Models

David Schmitt, AICP, *Senior Transportation Planner*; Paul Dorothy, PhD, PE, AICP, *Staff Consultant*; Randy Kill, PE, *Burgess & Niple*

Abstract. Operational level traffic simulation models are beginning to be used more and more in transportation planning. This is being facilitated through advances in computing technology making the interface between travel demand and traffic simulation models seamless and reducing overall run times.

Most traffic simulation models do not rely on the trip-tables that travel demand models rely on. Rather, they use probabilities to orient the traffic through intersections. This is sufficient for small traffic operation models, but does not work effectively for larger study areas. The developers of two of the largest travel demand software packages are working on products that join the travel demand model data to an operational level model.

It is desirable to have the trip data from the travel demand and operational models to be identical, or at least consistent. However, this has not been the case in practice. The authors are currently working on a process that shares the trip information between the travel demand model and the operational model. The operational model used for this study is INTEGRATION, which accepts trip table data and can assign it to a network with block-level of detail. This process is being used for a large Major Investment Study in Cleveland, Ohio with a 2025 horizon year.

After some struggling, the authors believe they have developed a successful “handshake” process. It involves taking a sub-area trip table from the travel demand model and applying correction factors (CFs). The CFs were developed using a unique validation process combining the travel demand model trip table, existing traffic counts and a matrix estimation process.

The authors will highlight several interesting comparisons. They will analyze the technical ease and validity of adjusting the travel demand model trip table prior to assignment by the operational model. They will also compare this process to a simplified process whereby a uniform seed matrix, consisting of 100 trips for all interchanges, is adjusted using a matrix estimation process. If possible, the authors would also like to compare their process to that soon to be developed by the TransCAD and TP+ software developers.

An Integrated Model for Planning and Traffic Engineering

Wolfgang Scherr, *Innovative Transportation Concepts, Inc.*; Dick Adams, *City of Lynnwood*; and Thomas Bauer, *Innovative Transportation Concepts, Inc.*

Abstract. This presentation/paper summarizes our experience in building and using the City of Lynnwood's "Base Transportation Model" (BTM). The BTM is an integrated data base, that provides input for different kinds of analysis:

- Macroscopic travel demand forecast and planning,
- signal timing optimization,
- implementation studies using microscopic traffic simulation.

The BTM builds bridges between traditionally separated fields: from the "planning tools" (static three-stage modeling) to the "engineering tools" (signal optimization routines, static LOS models as well as dynamic simulation). On the one hand, these conventional approaches are maintained, but on the other hand, their overall consistency and level of detail is increased, by means of data integration and data interfaces. The City's planning process from land use down to intersection LOS is streamlined. The software tools are VISUM for data management and demand modeling, VISSIM for microscopic simulation and both SYNCHRO and TEAPAC for signal optimization.

The presentation will give insight into different aspects of the integrated model:

- a geographically detailed node-link graph that covers the entire City street network
- interactive editors and data structures for intersection geometry and signal timing that are relationally embedded in the node-link-network
- the automated transformation of demand model results into microscopic simulation input
- bridging the gap between the rough node-link model and the microscopic "data hunger", (e.g. use of intersection templates)
- application of static and dynamic capacity constraint models

A High Fidelity Hybrid Traffic Simulator for Transportation Planners

Qi Yang, *Caliper Corporation*

Abstract. This paper presents a model for simulating traffic flow on planning networks. Using a “windowing” technique, this model can simulate different parts of a network at different levels of details. High fidelity microscopic simulation is applied to the highways and streets where detailed road geometry and signal control data are available; meanwhile mesoscopic and/or macroscopic simulation are applied to roads adjacent to the area of interest or where less detailed data are available. This hybrid simulation approach provides transportation planners a united simulation tool to analyze large scale planning networks by allowing for explicit trade-off between accuracy and computational efficiency.

This model features three types of modeling fidelity, namely, microscopic, mesoscopic, and macroscopic, that can be assigned to selected intersections and road segments; it supports a wide variety of networks and travel data; and it provides visual display of dynamic traffic data. In microscopic simulation module, movements of individual vehicles are modeled in detail based on car-following and lane-changing logic; in mesoscopic module, vehicles are collected into traffic cells and streams and their movements are simulated based on predefined capacities and speed-density functions; in macroscopic module, vehicle movements are projected based on estimated average travel time and delay without concerning vehicles’ positions inside a segment or a intersection. Using a geographical information system (GIS) based platform, the simulation model can import a wide range of networks and travel demand data. It has user friendly editing tools for (a) enhancing the accuracy of imported networks; (b) visualizing and editing (??) traffic surveillance sensors and signal controllers at urban intersections and freeways; (c) editing and factoring time-variant trip tables (travel demand data); and (d) creating tabular and graphic report from the simulation output based on user’s customization. In addition, the model can display dynamic theme map and data views for user selected variable(s) on any network objects, as well as animated vehicle movements. In the paper, we will present the modeling framework and briefly discuss the key elements, including its GIS platform, vehicle movement module, traffic management module, and measurement of effectiveness module.

Las Vegas network is used for a case study of the model. Microscopic module was assigned to major freeways and a few selected arterials, mesoscopic module for other major arterials and streets, and macroscopic module to the remaining local streets. The computational performance of the hybrid simulation is then compared with three homogenous simulations on the same network with all road segments and intersections designated to the same modeling fidelity.

Comparison between a Predictive and a Reactive Dynamic User Equilibrium Assignment Algorithm

Caroline Lemoine, *Ecole Nationale des Ponts et Chaussées*
and Morgan Mangeas, *LIVIC (INRETS-LCPC)*

Abstract. As traffic conditions are getting worse, the application of advanced traffic management systems (ATMS) is becoming commonplace. This is possible thanks to the engineering improvements made over the last decade. Because of the need to integrate ATMS into the transportation planning process, the use of simulation models is increasing.

In order to take into consideration drivers behavior some dynamic traffic assignment (DTA) algorithms have been proposed in the literature. In general, these assignment algorithms can be classified into two categories: “reactive” assignment and “predictive” assignment. The former uses “instantaneous” travel times assessed as the sum of link travel times along the path estimated at the time when drivers enter the path. The latter uses “experience” travel time calculated by the ‘floating vehicle method’. It considers time varying conditions all along the path and the impact of future traffic.

This paper compares these two previous methods using a second order macroscopic traffic model. The traffic model is an extension of Payne’s model. The interactions between links and spillback congestion are taken into account. Link interaction has been neglected in previous researches because it implies an asymmetric cost matrix so no proof of convergence can be given.

The two heuristic assignment algorithms are based on splitting rates of traffic flow for each destination at each network node. Both algorithms use the method of successive averages to calculate the splitting rates for the next iteration. The criteria used to test the convergence are those proposed by Papageorgiou (1990), Wang et al. (2001) and Huang and Lam (2002).

In the first section, the underlying traffic model is described and the assignment algorithms presented. Then, for a test network, the travel times between each origin and each destination are compared to the minimum travel time. This is done for each of the two methods. The convergence of the two algorithms is also evaluated. Finally, the paper shows that predictive approach is closer to a Wardrop-like assignment and more appropriate for planning purposes. Even though no mathematical proof of convergence is given, the “predictive” algorithm properly converges.

Validation of Operational Models

David Schmitt, AICP, *Senior Transportation Planner*; Paul Dorothy, PhD, PE, AICP, *Staff Consultant*; and Randy Kill, PE, *Burgess & Niple*

Abstract. While given proper attention with travel demand models, validation of traffic operation models has long been an overlooked subject. Typically, the process revolves around a calibration procedure where the user tweaks the network and driver inputs to mimic some elements of existing conditions. No quantifiable validation standards for operational models are known to the authors to exist in the United States.

Validation is more pressing with the advent of ‘meso-scopic’ operational models. These types of models combine the advantages of a vehicle Origin-Destination trip table with the micro-level detail of street geometry. They allow for much larger networks than previously available. They also expand their usefulness because they can now forecast at a planning level, looking beyond the typical 0-2 year horizon of the typical operational model.

The authors are working on a validation process for such a ‘meso-scopic’ model for a large Major Investment/Alternatives Analysis Study in Cleveland, Ohio with a 2025 horizon year. The study area is 17.5 square miles, making for a large network at 60,000 vehicles and 3,000 links. The validation criteria used were adapted from similar standards for a daily travel demand model and have already been applied with success to the regional travel demand model. These criteria are being applied to the ‘meso-scopic’ model for both the AM and PM peak hours. The criteria consists of the following:

- VMT by facility type
- Percent Root Mean Square Error (%RMSE) for all links
- %RMSE by volume groups
- Screenlines around the CBD
- R^2 analysis

The VMT, %RMSE, and Screenline criteria had to fall below pre-described levels for the results to be considered ‘valid’.

The presentation will cover:

- A brief explanation of the study area and the INTEGRATION model
- A description of the validation criteria
- Difficulties encountered during validation process
- Lessons learned from validating ‘meso-scopic’ models
- Lessons learned from forecasting with a ‘meso-scopic’ model

CORSIM, PARAMICS, and VISSIM: What the Manuals Never Told You

Fred Choa, P.E., Ronald T. Milam, AICP, David Stanek, P.E.

Abstract. With the increasing use of microsimulation traffic software in operations analysis, the need to identify which tool to use and the ability of the software to provide traditional traffic engineering measures of effectiveness consistent with the 2000 Highway Capacity Manual (2000HCM) has become a major area of debate. This paper provides a comparison of the three major traffic simulation software programs in use today and the results of the evaluation matrix developed by the authors for a freeway and interchange improvement project involving unique geometrics, ramp controls, and weaving constraints.

The three simulation programs considered in the paper are listed below:

- CORSIM, developed by the Federal Highway Administration (FHWA), is one of the most commonly used micro-simulation programs for modeling vehicle traffic operations.
- PARAMICS, developed by Quadstone Limited, a Scottish company, is a software program used to model the movement and behavior of individual vehicles and transit on local arterial and regional freeway networks.
- VISSIM, developed by Planung Transport Verkehr (PTV), a German company is one of the most sophisticated microsimulation software programs available and provides significant enhancements in terms of driver behavior, multi-modal transit operations, interface with planning/forecasting models, and 3-D simulation.

This paper describes the following key factors that may affect the decision on which software to use for a specific project involving a freeway interchange and the consistency of the model output to traditional traffic engineering measures of effectiveness.

- Model Development (i.e. input requirements and coding effort);
- Calibration to Field Conditions (i.e. driver behavior, traffic flow characteristics and traffic control operations);
- Validation Requirements (i.e. travel times, queue lengths and level of service);
- Animation (i.e. graphics, viewing options, and backgrounds); and
- Model Output and Consistency with the 2000 HCM.

The purpose of this paper is to provide transportation planners and traffic engineers with a comparison of the set-up requirements, model development effort, and analysis results for a typical freeway interchange study using the CORSIM, PARAMICS, and VISSIM microsimulation traffic software programs. This paper describes the following key factors that may affect the decision on which software to use for this type of project and the consistency of the model output to traditional traffic engineering measures of effectiveness.

- Model Development (i.e., input requirements and coding effort);
- Calibration to Field Conditions (i.e., driver behavior, traffic flow characteristics, and traffic control operations);
- Validation Requirements (i.e., travel times, queue lengths and level of service);
- Simulation / Animation (i.e., graphics, viewing options, and backgrounds); and

- Model Output and Consistency with the 2000 Highway Capacity Manual (HCM).

Description of Traffic Simulation Programs

Traffic simulation models are used in many cases to visually display analysis results and provide a system-wide analysis instead of isolated components (i.e., intersections, ramp merge / diverge, weaving sections, etc). Other common reasons for their use are to analyze complex or unique roadway geometries that other analysis programs cannot evaluate or to evaluate a combined system of arterial and freeway facilities. Three commonly-used traffic simulation programs in the United States are CORSIM, PARAMICS, and VISSIM.

CORSIM, developed by the Federal Highway Administration (FHWA), is one of the most commonly used simulation programs for modeling vehicle traffic operations. In addition, it is fairly standard practice to create CORSIM models using Synchro, a traffic signal optimization and coordination software developed by Trafficware. CORSIM is one of the programs included in the TSIS 5.0 software package. The package also includes TRAFED, a network editor, and TRAFVU, an animation software.

The TRAFVU program provides a two-dimensional simulation using rectangular shapes for cars, trucks, and buses. The colors for vehicles and the background can be adjusted using a limited color palette. Pedestrians are not shown in the animation, but do effect the operation of turning vehicles (although vehicles look like they are waiting for no reason). Various performance measures can be shown as part of the animation.

PARAMICS, developed by Quadstone Limited, a Scottish company, is a program used to model the movement and behavior of individual vehicles and transit on local arterial and regional freeway networks. But unlike the other microscopic simulation programs, PARAMICS is UNIX-based. But through the use of a Microsoft Windows-based software called Exceed by Hummingbird, the X-Windows platform is emulated on a standard workstation computer.

The PARAMICS Modeler program combines the network editing and visual animation tasks and allows for simultaneous editing and simulating. Both two-dimensional and three-dimensional animation can be performed using enhanced rectangular shapes for cars, trucks, buses, and trains. The model elements can be given a wide variety of colors, and the vehicle shapes can be customized. Additionally, a graphic file (such as an aerial photograph) can be shown as the background for the animation. A separate program, PARAMICS Analyzer, is used to visually display performance measures.

VISSIM was developed by Planung Transport Verkehr (PTV), a German company. Innovative Transportation Concepts (ITC) based in Corvallis, Oregon distributes and supports VISSIM throughout Northern America. VISSIM is one of the latest microsimulation software programs available and provides significant enhancements in terms of driver behavior, multi-modal transit operations, interface with planning / forecasting models, and 3-D simulation.

VISSIM provides animation capabilities similar to PARAMICS, with major enhancements in the 3-D simulation of vehicle types (i.e., from different passenger cars, trucks, transit vehicles, light rail and heavy rail). In addition, movie clips can be recorded within the program, with the ability to dynamically change views and perspectives. Other visual elements, such as trees, building, transit amenities and traffic signs, can be inserted into the 3-D animation.

The software acceptance issue is important to note because each simulation model is built upon a set of stochastic algorithms that attempt to represent traffic flow through various types of network systems under various conditions. This paper does not evaluate the different algorithms but does point out that reviewing agencies such as the California Department of Transportation (Caltrans) have been more likely to accept the use of simulation models that were built upon traffic flow conditions measured and modeled in the United States. But similar to the entire microscopic traffic simulation field, opinions are changing fast as products like VISSIM and PARAMICS are used more and more here in the US.

Description of Study Area

The study area for this evaluation is shown in Figure 1. Depicted in the figure are the geometrics, traffic control, and future (2025) peak hour traffic volumes associated with a proposed improvement project for the U.S. Highway 50 / Missouri Flat Road interchange near the historic gold mining town of Placerville, California. The existing interchange operates poorly and suffers from limited spacing between signalized intersections. After considering a variety of interchange improvement alternatives, a single point urban interchange (SPUI) design was selected as the recommended future interchange configuration. The SPUI configuration is unique in California, with only a handful of SPUI interchanges in operation. Therefore, extensive traffic operations and design analysis was required before local and State agencies accepted the design as the preferred project design in this location. The use of traffic simulation analysis tools was instrumental in the traffic operations analysis and served as the basis for this paper.

As shown in the figure, the study area extends east to include the U.S. 50 / Placerville Drive / Forni Road interchange. This interchange was included so that realistic weaving operations could be analyzed between the two interchanges, which are approximately ½ mile (800 meters) apart and connected by a bridge across Weber Creek canyon. The vertical sag on the bridge compounds the problem of the short weaving section length between the interchange by introducing grades of up to plus or minus eight percent for the interchange ramps. Although the original analysis included a substantial number of analysis locations, this paper focuses on a comparison of simulation model results for the following locations:

- U.S. 50 / Missouri Flat Road ramp terminal intersections;
- U.S. 50 / Missouri Flat Road eastbound off-ramp;
- U.S. 50 / Missouri Flat Road westbound on-ramp; and
- U.S. 50 westbound and eastbound weaving sections between the Missouri Flat Road and Placerville Drive / Forni Road interchanges.

Traffic Simulation Model Set-Up

As part of the traffic simulation model comparison, initial set-up times for the U.S. 50 / Missouri Flat Road interchange project were documented. Set-up times were compared because they are a good indicator of user-friendliness, learning curve requirements, and structure of the graphical user interface (GUI). In general, the set up times were similar with 3 to 4 days required to get each model coded and debugged. PARAMICS and VISSIM have more input parameters, which can improve the accuracy of the models, when compared to CORSIM.

For example, the path-based routing in VISSIM was used to better reflect lane utilization through the SPUI. The PARAMICS network editing tools were used to match the proposed turn radii at all intersections and ramp junctions. This type of refinement was not possible in CORSIM due to the link-based trip assignment and 50-foot minimum spacing requirement between nodes. As a result, an additional day was used to refine and complete the final set up for the PARAMICS and VISSIM models of the interchange.

Traffic Simulation Model Calibration and Validation

Calibration is the process by which the individual components of the simulation model are refined and adjusted so that the simulation model accurately represents field- measured and observed traffic conditions. The major components or parameters of a simulation model that require calibration include the following:

- Traffic control operations;
- Traffic flow characteristics; and
- Driver behavior.

This step should not be confused with validation; whereby the accuracy of the model is tested by comparing traffic flow results generated by the model with field collected data. Validation is discussed later in the paper and is directly related to the calibration process because adjustments in calibration are often necessary to improve the model's ability to replicate field measured traffic flow conditions (i.e., validation).

With regards to calibration, traffic simulation models contain numerous variables to define and replicate traffic control operations, traffic flow characteristics, and driver behavior. Simulation models contain default values for each variable, but also allow a range of user-applied values for each variable. In some cases, the variables affect the entire network while others are specific to individual roadway segments or nodes. Changes to these variables during calibration should be based on field-measured or observed conditions. *In other words, a change in the variables should be justified and defensible.*

Unfortunately, the user manuals for simulation models provide little or no information about the source or appropriateness of the default parameters, nor do they provide substantial guidance on how the user should modify these parameters for different types of conditions. Therefore, the user has a greater responsibility for ensuring that appropriate changes are made that are based on field-measured data and not exclusively on engineering judgment.

Under ideal conditions, the calibration of individual components of a simulation model will improve the model's ability to replicate traffic flow results that match field conditions within an acceptable range of error. Typical traffic flow characteristics that can be used in validation include traffic volumes, average travel time, average travel speed, queue lengths, and density. Unfortunately, professional guidelines that define the acceptable range of error for these characteristics have not been developed. Instead, transportation professionals have either ignored the need for validation or developed their own guidelines. Examples of validation guidelines used in recent projects by the authors and accepted by agencies such as Caltrans are contained in Table 1. Although these guidelines are a starting point for discussion, they lack statistical justification to determine if they provide an acceptable range of error.

Analysis Procedures

Because of the software's unique capabilities, default input parameters, and the stochastic nature of simulation programs, the same input information regarding roadway geometrics, intersection configurations, traffic control, and traffic volumes does not yield the same results. Calibration can help to minimize the potential differences between programs. However, many projects involve scenarios where transportation facilities are proposed in areas where they do not exist today or where transportation conditions are projected to change so dramatically that existing conditions are not expected to represent future conditions. Additionally, the method of calculating the performance measures differs between software programs and none of the programs provide a level of service analysis that is directly comparable to the 2000 HCM methodologies.

According to the 2000 HCM methodology, the level of service at an intersection is based upon average control delay on the approaches. The output files for CORSIM provide the control delay for each network link and the total delay for each turn movement. PARAMICS only provides total delay, not control delay, for each link and not for each turn movement. VISSIM is the most flexible and provides two ways to measure delay. The total delay can be measured between any two points in the network, or can be measured for each intersection turn movement using the node evaluation process.

Parameters	Description	Criteria
Volume Served	Percent difference between input volume and the simulation model output or assigned volume	95 to 105 % of observed value
Average Travel Time	Standard Deviation between floating car average travel times and simulated average travel time for a series of links	1 Standard Deviation
Average Travel Speed	Standard Deviation between floating car average travel speed and simulated average travel speed for individual links	1 Standard Deviation
Freeway Density	Percent difference between observed freeway density (from volume counts and floating car travel speed) and simulated density	90 to 110 % of observed value
Average and Maximum Vehicle Queue Length	Percent difference between observed queue lengths and simulated queue lengths	80 to 120 % of observed value

For freeway analysis, the 2000 HCM methodology uses freeway segment vehicle density to determine level of service. All three software programs allow for the measurement of density at a point on a link or for an entire link. CORSIM does not provide a direct estimate of density for each lane although the other two programs do. The density by lane is needed in ramp junction analysis to determine the density in the ramp influence area on a freeway with three or more lanes.

The U.S. 50 / Missouri Flat Road interchange improvement project described above is a good example of these problems and presented the authors the opportunity (and challenge) to conduct this simulation model comparison. In general, each program was used to set up a simulation model of the study area shown in Figure 1. The models used for comparison were limited to p.m. peak-hour vehicle traffic operations under 2025 conditions since higher traffic volumes were projected for the evening peak hour. In order to determine the effects of random seed numbers for the stochastic models, five runs were conducted with each simulation model and the averages for performance measures were summarized and compared. The results of the analysis are discussed in the next section.

Analysis Results Summary and Comparison

As stated above, the analysis results included the following locations:

- U.S. 50 / Missouri Flat Road ramp terminal intersections;
- U.S. 50 / Missouri Flat Road eastbound off-ramp;
- U.S. 50 / Missouri Flat Road westbound on-ramp; and
- U.S. 50 westbound and eastbound weaving sections between Missouri Flat Road and Placerville Drive / Forni Road.

Performance measures were extracted from each simulation model to determine the corresponding level of service (LOS) based on 2000 HCM procedures and methodology. Table 2 below compares the ramp terminal intersection LOS results while Table 3 compares

the ramp and weaving section LOS results. Although the LOS results are similar, key differences are worth noting.

<i>Table 2 - 2025 Intersection Operations Summary – 2025 Conditions</i>				
Intersection	Demand Volume	Percent Demand Volume	Delay (sec./veh.)	LOS
CORSIM				
Missouri Flat Road / Prospector’s Plaza Drive	3,333	98%	21	C
Missouri Flat Road / U.S. 50 Westbound Ramps	3,056	98%	5	A
Missouri Flat Road / SPUI	3,978	98%	28	C
Missouri Flat Road / U.S. 50 Eastbound Ramps	4,006	95%	3	A
Missouri Flat Road / Mother Lode Drive	4,128	99%	14	B
PARAMICS				
Missouri Flat Road / Prospector’s Plaza Drive	3,333	95%	22	C
Missouri Flat Road / U.S. 50 Westbound Ramps	3,056	95%	4	A
Missouri Flat Road / SPUI	3,978	93%	36	D
Missouri Flat Road / U.S. 50 Eastbound Ramps	4,006	93%	6	A
Missouri Flat Road / Mother Lode Drive	4,128	86%	26	C
VISSIM				
Missouri Flat Road / Prospector’s Plaza Drive	3,333	98%	20	C
Missouri Flat Road / U.S. 50 Westbound Ramps	3,056	98%	5	A
Missouri Flat Road / SPUI	3,978	100%	30	C
Missouri Flat Road / U.S. 50 Eastbound Ramps	4,006	100%	36	A
Missouri Flat Road / Mother Lode Drive	4,128	100%	9	A

For example, the PARAMICS model had lower values for percent demand served, which was caused by congestion through the SPUI associated with incorrect lane utilization. The problem stems from northbound vehicles on Missouri Flat Road destined for the westbound on-ramp being in the incorrect lane prior to reaching the SPUI intersection. This type of problem occurs because CORSIM and PARAMICS use link-based routing and is solved in VISSIM due to the use of path-based routing. PARAMICS currently has a limited look-ahead distance which allows vehicles to anticipate turn movements up to two links away. According to PARAMICS technical support, upcoming upgrades to PARAMICS will eliminate this type of problem. A similar problem also occurs in CORSIM but can be mitigated somewhat through the use of conditional turn movements. But this function is only limited to adjacent links.

In addition, sensitivity tests were conducted to better understand how minor changes in demand volume would affect the operations of the SPUI and the results of the microscopic traffic simulation. The simulation results for the ramp junctions were compared with analysis results from the Highway Capacity Software (HCS) to determine whether the results are comparable. The traditional HCM methodology has greater acceptance by many traffic engineers and transportation planners as long as the traffic volume inputs fall within acceptable ranges. Table 4 contains the HCS analysis results.

Table 3 - 2025 Ramp Junction and Weaving Operations Summary – P.M. Peak Hour (Traffic Simulation Results)		
Ramp Junction / Weaving Section	Density (1)	LOS
CORSIM		
U.S. 50 / Missouri Flat Road eastbound off-ramp	17.3	B
U.S. 50 / Missouri Flat Road westbound off-ramp	69.4	F
U.S. 50 westbound weaving section – Placerville Drive / Forni Road to Missouri Flat Road	18.2	B
U.S. 50 eastbound weaving section – Missouri Flat Road to Placerville Drive / Forni Road	21.4	C
PARAMICS		
U.S. 50 / Missouri Flat Road eastbound off-ramp	39.4	E
U.S. 50 / Missouri Flat Road westbound off-ramp	102.6	F
U.S. 50 westbound weaving section – Placerville Drive / Forni Road to Missouri Flat Road	33.4	D
U.S. 50 eastbound weaving section – Missouri Flat Road to Placerville Drive / Forni Road	36.6	E
VISSIM		
U.S. 50 / Missouri Flat Road eastbound off-ramp	26.4	D
U.S. 50 / Missouri Flat Road westbound off-ramp	59.0	F
U.S. 50 westbound weaving section – Placerville Drive / Forni Road to Missouri Flat Road	30.4	D
U.S. 50 eastbound weaving section – Missouri Flat Road to Placerville Drive / Forni Road	26.6	D
Notes: (1) Density is defined as passenger cars per mile.		

Table 4 - 2025 Ramp Junction Operations Summary – P.M. Peak Hour (HCS Results)		
Ramp Junction / Weaving Section	Density (1)	LOS
U.S. 50 / Missouri Flat Road eastbound off-ramp	36.0	E
U.S. 50 / Missouri Flat Road westbound off-ramp	33.0	D
Notes: (1) Density is defined as passenger cars per mile.		

After reviewing the HCS results and the graphic simulations for each simulation model, the following conclusions were reached:

- Weaving results from CORSIM underestimated density and LOS. For example, even using the latest version CORSIM (i.e., TSIS 5.0) the CORSIM model interface node (between NETSIM and FRESIM networks) at the westbound on-ramp from Placerville Drive / Forni Road creates an artificial bottleneck that meters traffic entering the freeway which creates gaps in the platoons from the

on-ramps that do not actually occur. This situation creates unrealistic traffic flows through the westbound weaving section.

- The PARAMICS and VISSIM models did not have this problem and provided more reliable simulations of freeway on-ramps, ramp junction and weaving sections.
- Ramp junction results from CORSIM underestimated the density and LOS for the eastbound off-ramp. The 2025 freeway volume approaching this ramp is 3,165 vehicles in two lanes of which 1,155 vehicles are diverging to the off-ramp. LOS B as calculated based on the CORSIM results is not consistent with these volumes.

Conclusions

The traffic operations results for this specific project should not directly applied to all interchange projects because of the unique design of a SPUI and the wide variety of input parameters and their ranges. However, this comparison paper does point out the importance in choosing the right simulation analysis tool and determining the applicability of simulation model results when using only one model.

The following conclusions summarize the results of comparing three of the most used traffic simulation programs:

- CORSIM provided the shortest set-up time. Both PARAMICS and VISSIM required about an additional day for model refinement.
- Both CORSIM and PARAMICS use link-based routing which can result in inaccurate lane utilization for closely-spaced intersections. The path-based routing in VISSIM eliminates this problem.
- Both PARAMICS and VISSIM provide three-dimensional animation although VISSIM has more options for enhancing the visual setting. The CORSIM two-dimensional animation is more simplistic.
- No software provides average control delay for each turn movement although CORSIM does provide average control delay for each approach. All report total delay by link.
- CORSIM has an artificial barrier between arterial and freeway networks that can cause inaccuracies such as the “metering” of traffic on high-volume on-ramps or “backups” of traffic on high-volume off-ramps.
- Overall, PARAMICS and VISSIM generated simulation results that better matched field observed conditions, traffic engineering principles, and expectation / perception of reviewing agencies including Caltrans.

The results show substantial differences between the three microscopic traffic simulation models. If only one model were applied, the user would likely accept the results unless the graphic simulation displayed unexpected results. Reviewing the results from all three models raises the obvious question, “Which model is correct?” Or, the question could be phrased as, “Are any of the models correct?”

The user manuals do not include information about the thoroughness of software testing for various types of projects or situations. In other words, software documentation or user

manuals do not provide the information traffic engineers and planners need to answer the critical questions or to determine the reliability of the simulation results.

Endnotes

(1) Transportation Research Board, Highway Capacity Manual (HCM), Fourth Edition, 2000.

Analysis of Impacts of Pricing on Tacoma Narrows Bridge

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Resource Systems Group

Abstract. The existing Tacoma Narrows Bridge is a four-lane structure crossing the Puget Sound near Seattle, Washington. The bridge is currently operated toll-free. The proposed improvement project would add a parallel span and increase the capacity of the bridge to six lanes (three in each direction), as well as provide other roadway improvement in the immediate vicinity of the bridge and seismic upgrades to the existing span. Tolls would be collected on the new span only, covering all southbound/eastbound traffic.

As part of the traffic and revenue analysis for the improvement project, a detailed analysis of the impacts of imposing pricing on the currently free crossing was conducted. Extensive origin-destination data were collected on the bridge and competing vehicle ferries. A stated preference (SP) survey was conducted to provide input regarding motorists' value of time and willingness to pay tolls. The SP surveys were used to develop model formulations to assess the potential level of trip reduction in response to pricing on the bridge. In addition to route diversion and diversion to ferries, a reduction in the number of trips being made on an average daily basis could take the form of various reactions:

- Shifts to alternative modes;
- Shifts to alternative destinations on the same side of Puget Sound;
- Trip consolidation;
- Trip elimination.

The traffic impact analysis of pricing on the bridge involved three steps:

- Use of the regional travel demand model to develop base year trip tables and corridor growth rates for bridge traffic;
- Development of trip reduction factors to estimate levels of reduced travel demand due to the imposition of tolls; and
- Development of estimates of traffic diversion to alternative routes and ferries.

The model formulations developed from the stated preference surveys were applied directly to trip tables representing bridge traffic that were developed from the origin-destination surveys to develop a series of reduced travel scenarios at a variety of toll rate levels and forecast years. The travel pattern data from the origin-destination surveys conducted on the bridge were merged with the trip tables from the regional travel demand model in order to run traffic assignments on the regional highway network.

The analysis showed reduced tripmaking in the range of 3-9 percent, depending on trip purpose and toll rate level, with an additional 10 percent reduction in traffic crossing the bridge in the tolled direction due to diversions to alternative routes and ferries. At 2010 levels, a net reduction of 10 percent in two-way daily traffic was forecasted.

The existing Tacoma Narrows Bridge, built in 1950, is over 5,400 feet long and carries two narrow traffic lanes (see Figure 1) in each direction. The bridge is currently operated toll-free. The proposed improvement project, to be completed by 2007, would add a new bridge adjacent to the existing structure, provide interchange and other highway



Figure 1 - Tacoma Narrows Bridge

improvements near the crossing, and provide a seismic upgrade to the existing span. When the project is completed, both spans will provide three 12-foot travel lanes in each direction, two shoulders, and a separated bicycle/pedestrian lane. One of the lanes in each direction will be designated as an HOV lane. To provide financial support for these improvements, tolls will be re-established on this crossing. Tolls were originally removed from the existing bridge in 1965. Tolls will be collected on the new span only, covering all southbound/eastbound travel. HOV traffic will not be

tolled. The primary purpose of our study was to estimate traffic and toll revenue potential for use in support of project financing.

Study Area

The Puget Sound was a major driving economic force in the development of the region, providing access to international trade markets via its active ports. However, Puget Sound has also presented a major challenge for transportation within the region. As shown in Figure 2, most of the major development has occurred, over the years, to the east and south of Puget Sound. The region's largest city, Seattle, is located along the eastern edge of Puget Sound. The city of Tacoma, with its major port and industrial facilities, is located in the southeastern portion of the Sound. The Kitsap Peninsula, which includes most of Kitsap County and parts of Pierce and Mason Counties, forms the western shore of Puget Sound. Economic development on the Peninsula has taken the form of residential communities from which workers commute to Seattle and Tacoma, and major facilities supporting the military, including the Puget Sound Naval Shipyard in Bremerton and a submarine base at Bangor.

The major freeways serving the Seattle-Tacoma region are also shown in Figure 2. I-5 passes through the entire area on the east side of the Sound. From the region, I-5 extends southward to Olympia toward Portland, Oregon and northward through Tacoma, Seattle toward the Canadian border. I-405 is part of an urban belt system passing through Bellevue along the eastern side of Lake Washington, and serves as a bypass of the city of Seattle. I-90 provides access between the Seattle-Tacoma region and the Spokane area and other points east. State Route 16 is a limited-access facility that provides access between Tacoma and Bremerton. The Tacoma Narrows Bridge is a critical link of S.R. 16 as it crosses the Puget Sound.

The Tacoma Narrows Bridge is the only fixed roadway link crossing the Puget Sound between Tacoma and the Kitsap and Olympic Peninsulas. The only other means of reaching the Kitsap and Olympic Peninsulas from Seattle and the east side of the Sound is by ferry or via a circuitous land route using Routes 101 and 3.

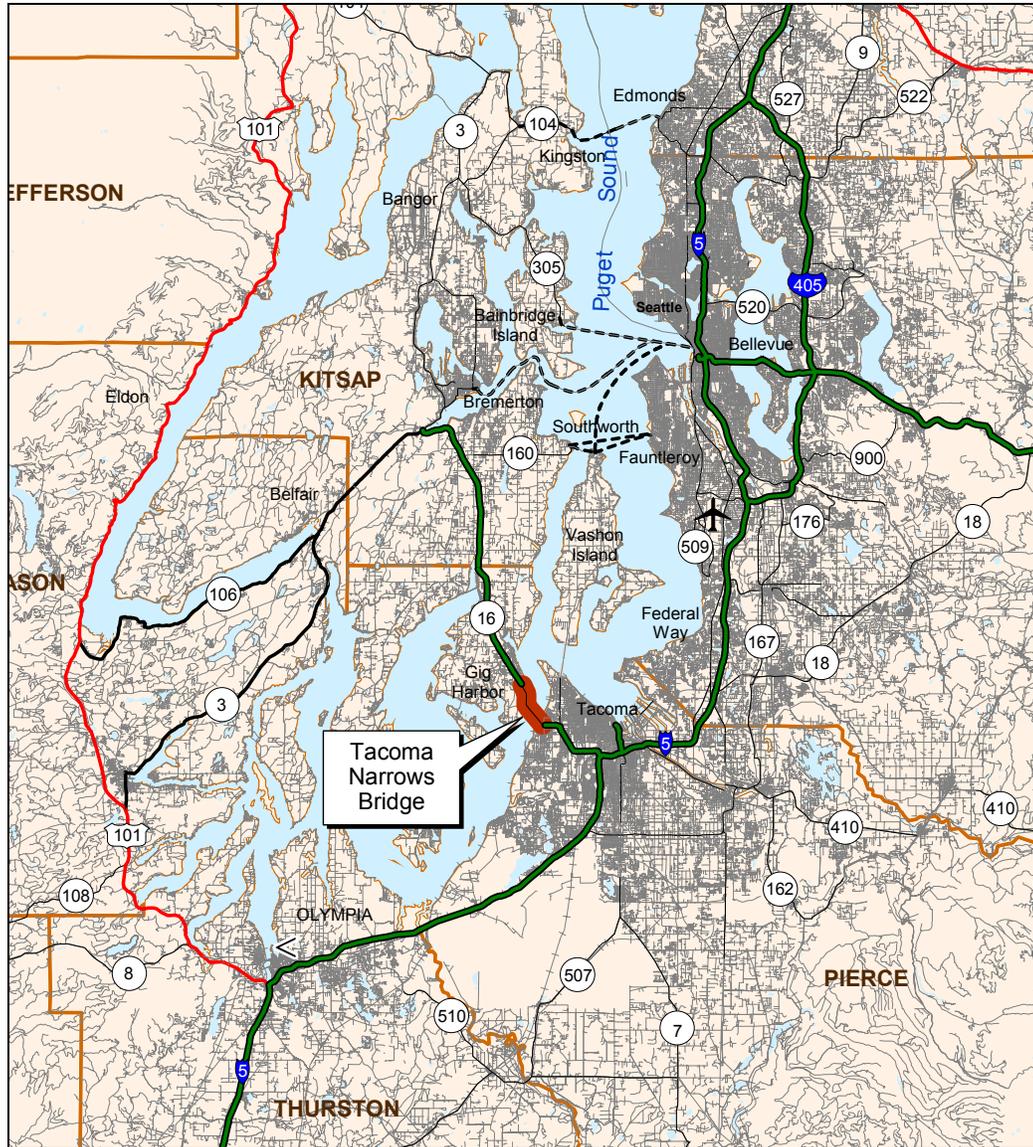


Figure 2 - Study Area

Study Approach

The study approach integrated existing traffic volume data, travel pattern data from origin-destination (O-D) surveys, behavioral information from stated preference surveys, and updated regional socio-economic forecasts within a regional travel demand modeling context to estimate traffic volume under varying toll levels on the Tacoma Narrows Bridge.

A summary of the analysis methodology is shown in Figure 3. The flow of data from various sources into the process is shown. The O-D surveys were used to develop a matrix of trips using

the Tacoma Narrows Bridge, which were subjected to varying toll rate assumptions and merged with background trips from the regional travel demand model before running toll-free and tolled traffic assignments. The travel demand reduction model was used to estimate the overall level of reduced tripmaking of Bridge users at different toll rates. Reduced tripmaking accounted for changes in travel behavior that would result in fewer trips across the bridge, such as trip consolidation, change of destination, switching to bus or carpool, and eliminating trips.

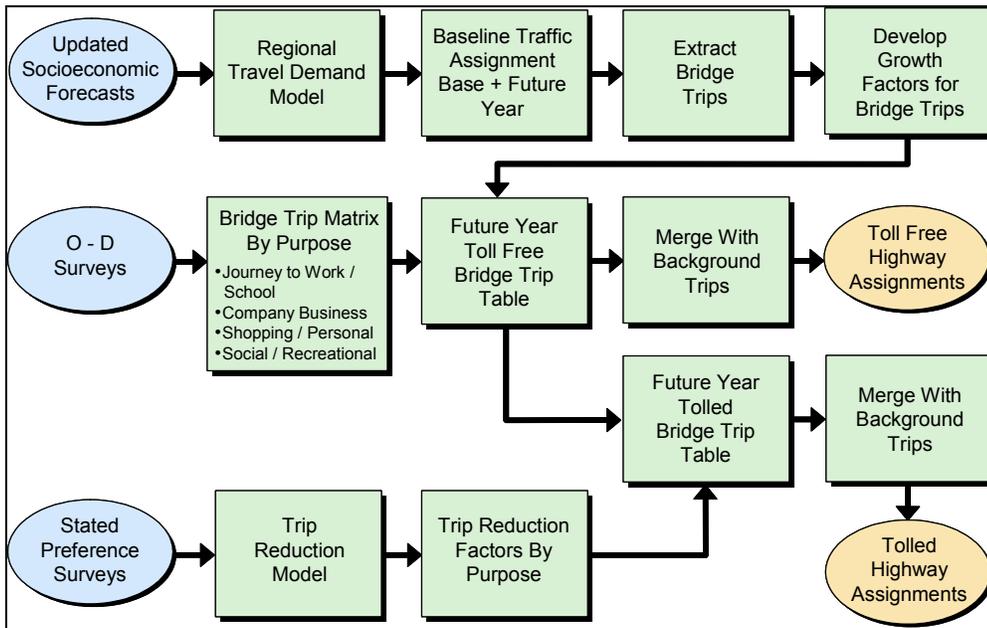


Figure 3 - Analysis Methodology

The reduced bridge trip tables were merged back with the background trips from the regional demand model and the combined trip tables were assigned to the highway network under toll-free and tolled conditions. The highway network included links representing the ferry routes. Toll revenues were calculated from the tolled assignments for various future years to develop an annual revenue stream for the project.

Existing Traffic Trends

Figure 4 shows annual average daily traffic trends (total two-way traffic) on the Tacoma Narrows Bridge and four of the competing Washington State ferry routes (totaled). Overall, traffic on the Tacoma Narrows Bridge increased from 70,112 vehicles per day (vpd) in 1991 to 84,617 vpd in 2001, an average annual growth rate of 1.9 percent per year. The average growth rate during the first five years of the decade was 2.4 percent, in contrast to 1.4 percent per year for the period from 1996 to 2001. A similar pattern is observed in the vehicular ferry traffic, which averaged 1.6 percent growth per year during this ten-year period.

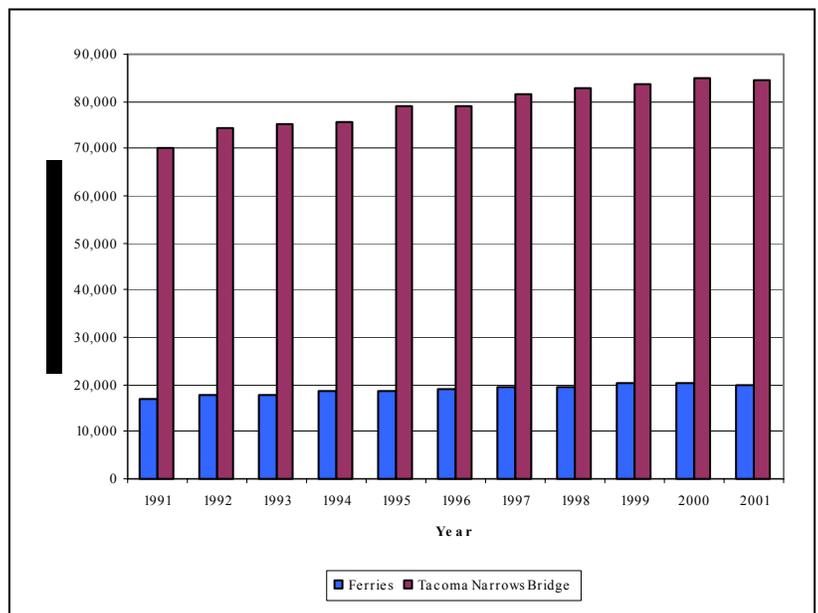


Figure 4 - Trends in Annual Average

The four competing ferry routes combined carried a total of 20,018 vpd in 2001. In 2001, the bridge carried 81 percent of all vehicles crossing the Sound.

The slowing growth over recent years can be attributed to a slowdown in the economy in the region and, to some extent, peak period capacity constraints on the bridge.

Existing Travel Patterns and Characteristics

A comprehensive motorist travel pattern and trip characteristic survey was conducted in June 1996. The primary objective of this survey was to obtain a “real world” and up-to-date measure of travel patterns of motorists who could be potential users of an improved S.R. 16 corridor. Surveys were conducted on the Bridge, competing Washington State Ferries, and on Routes 101 and 3 to capture the potential travel market for the bridge.

Trip Purpose - Work and school commute trips accounted for 43 percent of trips crossing the Bridge on a typical weekday. Company business trips accounted for 8 percent of trips, social/recreational accounted for 22 percent of trips, and shopping and personal business trips combined accounted for another 22 percent of trips. The remaining five percent of trips were in the “other” trip purpose category.

Vehicle Occupancy - Of the passenger cars surveyed on the Bridge, 62 percent were single-occupant vehicles. The average vehicle occupancy was 1.6 persons per vehicle.

Origin-Destination - Figure 5 shows the distribution of eastbound weekday trips on the Tacoma Narrows Bridge. On the north side of the Bridge, more than 57 percent of trips began in the southern portions of the peninsula. An additional 30 percent originated in the greater Southworth/Bremerton area. On the destination end, the local Tacoma area accounted for 43 percent of trips on the Bridge. Other points in southern Pierce County accounted for another 25 percent of Bridge trips. Seattle and points north and northeast accounted for only 11 percent of trips using the Bridge. Most trips oriented to these areas from the peninsula use the ferry system, which runs on 30 minute headways during peak hours. Even so, as much as one third of cross-Sound trips oriented toward the Seattle area use the Tacoma Narrows Bridge.

Stated Preference Surveys

Under a toll-free condition, significant levels of traffic now use the Tacoma Narrows Bridge. An important element of this study was estimating how this traffic might be impacted by the imposition of tolls. Since the Bridge is primarily the only realistic driving option for many movements, the only other choices for people to avoid a toll is to make fewer drive alone trips across the bridge. This can be accomplished in a number of ways, including combining or consolidating trips, which means that instead of making multiple trips across the bridge, a person would chain together multiple stops and make fewer trips to accomplish the same tasks; eliminating trips, which means that a person would forego a trip altogether; and changing the destination of the trip, which means that a person would still make the trip, but stay on the same side of the Puget Sound. The extent to which these and other trip reduction measures can be taken given the specific land use development patterns of the region was one of the primary purposes of the stated preference survey. The other primary purpose of the survey was to help determine motorist's willingness to pay tolls.

Survey Approach and Design - Computerized surveys were conducted involving travelers who cross between the Kitsap Peninsula and Tacoma/Seattle on the mainland. Direct interview surveys were conducted at a variety of activity centers on the Peninsula and a postcard invitation was mailed to a random sample of Peninsula residents. The postcard provided instructions for participation via the Internet. Invitations to the Internet survey were also provided to employees of several large employers in the Kitsap Peninsula and Tacoma area.

The computerized approach allowed the survey to be customized to the responses given. The questionnaire consisted of four main sections: Trip Description; Travel Alternatives Information; Stated Preference Questions; and Debrief and Demographics. In the survey, respondents were asked to describe the trips that they made between the Peninsula and the mainland. All participants were asked to indicate the frequency of trips for each of four trip purposes: work or school commute; company business; shopping or personal business; and social or recreational. One of the trips was selected at random and respondents were requested to provide additional information about their trips for the selected purpose. Then the participants were given a series of informational screens describing the Bridge Improvement Project and some changes to the Washington State Ferries system that might affect their travel choices in the future.

The stated preference questions presented respondents with eight sets of hypothetical scenarios, customized to each respondent based on the detailed information provided in the first section for a randomly selected trip. Each of the eight scenarios showed the three main alternatives with changes in travel conditions:

- Tacoma Narrows Bridge (varying time and cost),
- Ferry (varying time and cost), and
- Route 101 (varying time).

Five additional alternatives for which the travel information did not change were also shown:

- Taking a bus,
- Adding riders,
- Changing destination location,
- Combining or compressing trips, and
- Eliminating trips.

Respondents were asked how their travel choices and patterns would change under each of the eight sets of conditions. The scenarios were structured so that the information collected could be used to statistically estimate coefficients of a travel behavior model. The actual numbers shown to the respondent were customized to the trip information they provided in the first section of the survey.

If the trip that was randomly selected for the survey participant to respond about was an infrequent trip, they were asked in the stated preference section to select the travel alternative they would most likely choose for that trip from the list above.

Frequent travelers were asked to allocate the trips they make for the selected trip purpose among the alternatives in the list. A sample screen from the stated preference section for frequent travelers is shown in Figure 6. In this example, the respondent made four business round-trips per week. The respondent could answer under the travel time and pricing combination shown that he/she would make three of those trips across the Tacoma Narrows Bridge and would combine/compress one of those trips with another trip. The percentage of trips that a respondent would make by each alternative was used in the analysis. For infrequent travelers, 100 percent of trips were allocated to the indicated choice.

Kitsap Peninsula Transportation Study Tacoma Narrows Bridge and Travel Alternatives

Under these conditions, how many of your 4 WORK-RELATED BUSINESS ROUND trips would you make by each option?

Option 1: IMPROVED TACOMA NARROWS BRIDGE	Option 2: FERRY	Option 3: ROUTE 101	Option 4: OTHER
Trip takes 1 hr. 20 mins. each way	Trip takes 3 hrs. each Way (including getting to and from ferry)	Trip takes 3 hrs. 20 mins. each way	If any trips would not use option 1, 2, or 3, indicate how many would be:
Round trip toll is \$2	Round trip fare is \$1	No toll	<input type="checkbox"/> RIDE BUS (WITH PARK & RIDE)
I WOULD MAKE <input type="radio"/> 0 <input type="radio"/> 1 <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 <input type="radio"/> Other, specify: <input type="text"/>	I WOULD MAKE <input type="radio"/> 0 <input type="radio"/> 1 <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 <input type="radio"/> Other, specify: <input type="text"/>	I WOULD MAKE <input type="radio"/> 0 <input type="radio"/> 1 <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 <input type="radio"/> Other, specify: <input type="text"/>	<input type="checkbox"/> SHARE RIDE WITH OTHERS
ROUND TRIPS USING THE IMPROVED TACOMA NARROWS BRIDGE	ROUND TRIPS USING A FERRY	ROUND TRIPS USING ROUTE 101	<input type="checkbox"/> GO TO A DIFFERENT LOCATION
			<input type="checkbox"/> COMBINE/COMPRESS TRIPS
			<input type="checkbox"/> ELIMINATE TRIPS

Numbers in red change for each question Question 1 of 8

Figure 6 – Sample Stated Preference Survey Screen

The final section of the survey collected demographic data that were used to determine differences in responses among different traveler segments. This section also included attitudinal questions regarding improvements to the Bridge and ferries, and funding for the improvements. The responses to these questions allowed for the detection of intended bias in the data that could be accounted for when estimating the model.

Statistical Model Results - The stated preference data were used to support estimation of coefficients of a multinomial logit-based mode choice model. A total of four trip purpose segments

were identified and modeled separately: work and school commute; company business work; shopping and personal business; and social and recreational trips. For the work/school commute and company business work purposes, separate models were developed for frequent and infrequent travelers. Each of the six markets included trips made by residents of the areas on either side of the Bridge, and visitors to the region.

A sample set of model coefficients is provided in Table 1 for the work/school commute trip purpose. The constants for the bridge, ferry, and inland route were calibrated using the entire O-D survey dataset (including Bridge, ferry, and inland route surveys) to reflect the existing distribution of trips among these three alternatives. The constants for the other travel choices were adjusted based on the changes made to the three base alternatives.

The form of the mathematical equations of the model also contains a nested structure, in which similar modes are grouped together. Within nests there is a higher degree of competition than between nests. For this model, the Bridge and ferry modes were grouped into the same nest.

Parameter	Units	Coefficient
Time	minutes	-0.0302
Cost*	dollars	-0.6548
Ferry constant	0,1	0.6280
Route 101 constant	0,1	-3.1850
Bus constant	0,1	-9.0325
Add rider constant	0,1	-8.1865
Change destination constant	0,1	-8.6975
Combine trips constant	0,1	-3.4455
Total travel time by Bridge - for combine trip option	minutes	-0.1256
Eliminate trip constant	0,1	-2.9220
Total travel time by Bridge - for eliminate trip option	minutes	-0.0269
Nest theta	--	0.4197

*Divide cost by log of income in thousands

The implied value-of-time for travelers was also developed by comparing the coefficients from the model. Since the value-of-time will be used in the tolled traffic assignment process, separate models were estimated using only those responses that would choose to continue driving on any of the three main alternatives (responses that involved trip elimination or consolidation were removed from the dataset). The values-of-time derived from the models (for a \$50,000/year income level) ranged from \$6.39 per hour for social and recreational trips to \$12.10 per hour for frequent work commute trips to \$18.56 per hour for company business-related work trips. Based on the statistical modeling, the values-of-time derived from the models would vary with income levels for most purposes.

Traffic Analysis

The analysis phase of the study involved three steps:

- Refinement and use of the regional travel demand model to develop base-year trip tables and corridor growth rates for Bridge traffic based on updated land use and socioeconomic assumptions;
- Development of a travel demand reduction model to estimate levels of reduced travel demand due to the imposition of tolls; and
- Development of estimates of traffic diversion to alternative routes/ferries.

The flow of steps to accomplish these tasks was shown earlier in Figure 2.

The travel demand model used by the Pierce County Department of Public Works was used as the backbone for the analysis. This model is derived from the regional MPO's model but has added detail in Pierce County, where the Tacoma Narrows Bridge is located. The highway network for the model was expanded to include parts of Thurston and Mason Counties to include the inland travel route, Route 101 and 3, into Kitsap Peninsula. O-D surveys were also conducted on these two roadways to provide a full screenline of travel to and from the Peninsula.

The O-D surveys were coded to the zone system used for this study and extracted using the following breakdowns:

- Passenger car vs. commercial vehicle;
- SOV vs. HOV (for passenger cars only);
- Work (including commuting and business) vs. non-work (shopping, social, recreation, other); and
- Time of travel (a.m. peak period, p.m. peak period, and off-peak period).

The survey trips tables were merged with the regional model's base year trip table and validated against observed traffic volumes and travel times on the Tacoma Narrows Bridge and ferries. The intent of the merging process is to integrate the real-world travel patterns from the surveys with the patterns generated synthetically through the travel demand modeling process. Since the travel demand on the Bridge and ferries are considered to be "mature", the actual travel patterns from the surveys were also used in future-year trip tables by repeating this merging process for all future years. Prior to merging with the background trips at future year levels, a series of future year baseline assignments were run. Traffic crossing the Bridge, ferries, and inland routes were extracted and growth rates for these movements were developed at a district level. These district-level growth rates were applied to the trips developed from the O-D surveys before they were merged. These merged trip tables were used as a measure of normal growth for the Bridge and ferries in the absence of future tolling.

Travel Demand Reduction Model - A spreadsheet model was constructed to calculate the effects of different levels of pricing on bridge travel demand. The utilities of each of the travel options are defined using one or more of the following parameters:

- Trip purpose;
- Trip frequency;
- Travel time;
- Travel cost;
- Household income (effect for certain trip purposes only); and

- Mode constants (different for each option).

The six models estimated from the stated preference surveys were applied to a database of travel pattern information developed from the O-D surveys on the Tacoma Narrows Bridge only, since only these trips would be subject to a change in travel costs. Each record of this database represents a specific number of trips between a specific pair of origin and destination zones, for a specific trip purpose, at a specific trip frequency level. The model formulation corresponding to the trip purpose and frequency characteristics of each survey record was applied to the number of trips represented by the record. The estimated net reduction in tripmaking due to tolling is the sum of the impacts estimated for all records. For the purposes of the travel demand reduction model, the choices of alternative routes and ferries (assuming that people would drive their cars onto the ferries) would not reduce the overall level of tripmaking. The choice among those options that allow drivers to continue driving (Bridge, alternate route, and ferry) was estimated in the traffic assignment portion of the analysis.

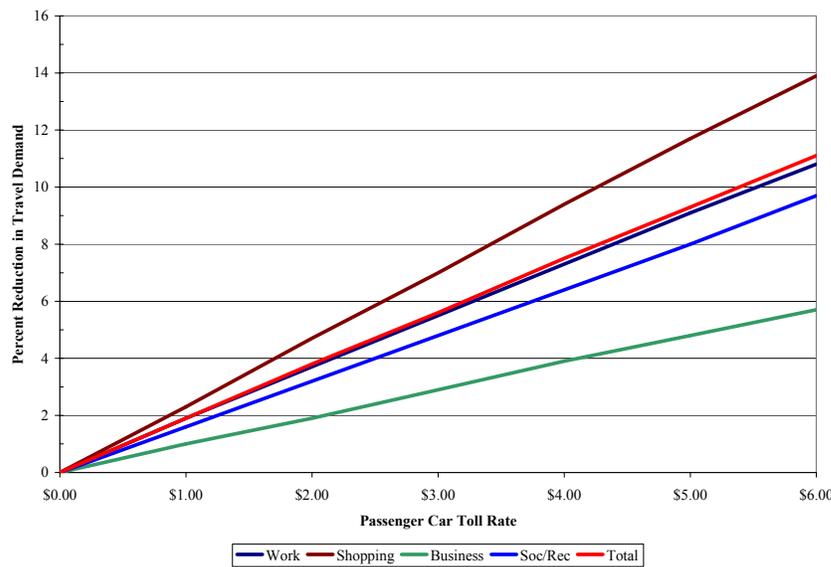


Figure 7 – Percent Reduction in Trips by Purpose and Toll Rate

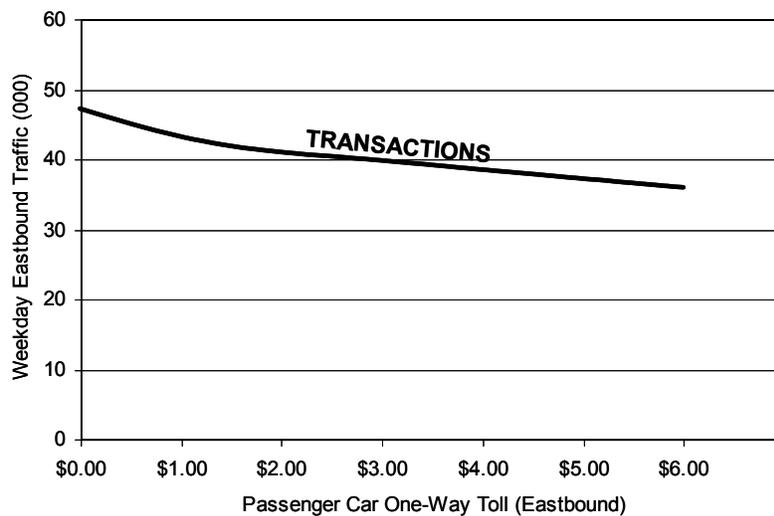
The net travel demand reduction factors at varying toll levels (in 2000 dollars) for the four different trip purposes are shown in Figure 7. The least sensitive trip category is the company business-related trips, which is not unexpected, since the costs for this type of trip tend to be reimbursed by the employer. The most sensitive is the shopping/personal business trip, which tends to be the most discretionary and chaining/consolidation or elimination. Social and recreational trips were less sensitive than shopping trips

because they tend to have limited alternative destinations and are less frequent so increased costs are not as much of a determining factor in whether the trip is made.

Results - The reduced Bridge trip tables were then merged with the background trips retained from the regional model trip tables for various future years. The merged trip tables were assigned to the regional highway network using an equilibrium capacity-constrained assignment process. The estimated toll-free trip tables were used for toll-free assignments for baseline estimates of growth on the bridge and the “reduced demand” trip tables, which incorporate travel demand reduction factors associated with the anticipated base toll levels for the Tacoma Narrows Bridge, were used for tolled highway assignments. Under the tolled condition, the highway assignment process also added a toll diversion feature which compared the attractiveness of the Bridge routing against the ferry and inland route driving options, considering travel time, cost and distance traveled. Multi-class assignments were made since HOV traffic would be allowed toll-free access to the bridge.

Figure 8 summarizes the sensitivity of traffic assigned to the Bridge for a range of toll rates, from \$1.00 to \$6.00 at 2005 levels. Due to the limited nature of alternatives for travel, traffic on the Bridge is relatively inelastic to toll changes within this range. While the ferry system would offer a somewhat competitive mode for some trips, the fares charged on the ferry system would be \$18.00 for a roundtrip for a vehicle and driver.

Under toll-free conditions, 47,000 vehicles are forecasted to travel eastbound on the Bridge on an average weekday. At a \$3.00 toll level, daily eastbound traffic volumes would be reduced by 16 percent to 39,500 vehicles per day. At \$6.00, traffic is estimated to be about 35,500 vehicles per day, or 24 percent lower than toll-free volumes. These traffic impacts reflect both reduced levels of trip making and diversions to/from the ferries and inland routes.



The reduction of travel demand across the bridge is estimated to account for 35 percent of the total eastbound trip loss at the \$3.00 toll level, which is the anticipated toll level at opening year. At the \$6.00 toll level, 45 percent of the total reduction in trips crossing the bridge is estimated to be from reduced travel demand. The rest of the loss would be from traffic shifting to ferries or to the inland route.

Conclusions

A travel demand reduction model was developed for the Tacoma Narrows Bridge to estimate the amount of reduction in trip generation due to tolling an improved bridge crossing. The impacts from the model were applied to trip tables based on actual origin-destination surveys from the bridge. The reduced trip tables were merged with the background regional trip tables and assigned to the regional highway network to estimate additional shifts to alternate routes and ferries. The methodology developed for this study incorporated results from surveys conducted specifically for the study while making maximum use of the regional planning agency's transportation model.

Tolls on the Tacoma Narrows Bridge have been estimated to reduce total traffic volumes in the tolled direction by about 16 percent at the \$3.00 toll rate level anticipated for 2007, the first year of toll operation following the completion of bridge improvements. Total two-way traffic would decrease by about 10 percent, after taking into account the smaller level of change in the toll-free direction. Of this, approximately 35 percent, or about 5.6 percent, would be due to a reduction in travel demand across the bridge associated with changes in travel destinations, trip consolidation, trip elimination. While shifts to carpool and bus transit are also an option, they would account for a very small amount of the change.

The Economic Benefits of a Roadway

Sandy Wesch-Schulze, P.E., AICP, *Carter & Burgess, Inc.* and Elizabeth Morris, *Insight Research Corporation*

Abstract. Environmental studies and analyzes are prepared to document existing social, economic and environmental conditions and assess of the effects of a proposed project. These documents are designed to help decision-makers assess the potential affects of the alternatives under consideration. The current regulations and guidelines place a heavy emphasis on documenting social and environmental implications, which are usually negative impacts (i.e., displacements). However, almost no emphasis has been placed on quantifying the economic, employment, and tax revenue benefits of a project.

For the Eastern Extension of the President George Bush Turnpike (PGBT) EIS, an economic model was developed to examine and compare the economic, employment and tax revenue effects and public cost/benefit potential of two possible alignment alternatives plus the No Build Alternative. This study compared the potential for market-driven development opportunities created by the proposed 10-mile tollway, which would extend east from State Highway 78 to Interstate Highway 30, passing through the cities of Garland, Sachse, and Rowlett in Dallas County, Texas.

The economic study corridor was defined as 220 yards or 660 feet outside the right-of-way for each alignment. Private commercial development opportunities were evaluated along each proposed alignment corridor for the size, type, and timing of land uses which could be reasonably expected for each. Only those changes in the character of land use which could clearly be related to the PGBT public investment were used for computing new opportunity. Under the No Build Alternative, it was assumed all properties would remain in their current taxable status. In the No Build Alternative, only those commercial market driven opportunities which are likely to occur within the available areas of the designated study corridor were forecast. The impacts of each alternative were examined and results compared over a 26-year development period using state-of-the-art econometric models to analyze various aspects of the total project's capital and operating costs.

The results of these analyses quantify four types of benefits that could be expected to accrue to the Dallas area and local governmental jurisdictions. The model computed economic impact, employment impact (direct and indirect), tax revenue impact (direct and indirect), and net public cost/benefit. Cash flow and break-even diagrams were developed to highlight the revenue streams resulting from the forecasted development. While the level of engineering difficulty, right-of-way acquisition, and construction costs were roughly similar for the two alternatives, they resulted in quite different land use and dramatically different economic impact potentials.

This information has been included in the Draft EIS for the project. Understanding a project's economic, employment and tax revenue impacts along with the implications to the social and natural environment will help elected officials and decision-makers understand all aspects of a project – both positive and negative. It will also help develop funding strategies and allies for the financing needed for any transportation improvements.

Gowanus Expressway HOV Lane Evaluation

Robert H. Brakman, PE, and Peter G. King, PE

Abstract. The Gowanus Expressway is the only limited access commercial arterial in Brooklyn, NY, and the only link to the Interstate System in Brooklyn. This unique role makes the Gowanus Expressway an essential link for the movement of people and goods through western Brooklyn and the New York City metropolitan area.

In 1976, the New York City Department of Transportation (NYCDOT) implemented a priority lane (designated as the "Blue Lane") for buses and occupied taxis on the Gowanus Expressway between 72nd Street and the Gowanus Expressway/Shore Parkway Interchange. In December 1996, reconstruction of the Prospect Expressway Interchange was initiated. As part of the Maintenance and Protection of Traffic Plan, the Gowanus' discontinuous sections of concurrent and contraflow priority lanes (the Base Condition) were connected by a contraflow priority lane, resulting in a continuous Bus/HOV 2+ lane between 72nd Street and the Brooklyn Battery Tunnel (BBT). An Intelligent Transportation System (ITS) was also inaugurated for the interchange area. The contraflow HOV lane was to be in place only through the period of interchange construction so as to serve as a construction impact mitigation, and was restricted to buses, taxis, and other vehicles which had at least two occupants (Bus/HOV 2+). In February 1997, the requirement that all vehicles using the lane be equipped with E-ZPass was added.

During the Prospect Interchange construction period, it was observed that traffic using the HOV lane flowed more smoothly and with fewer incidents than before construction began. Transit providers, and others who used the special lane, asked that the lane continue after construction was completed. A study was undertaken to review the utility of maintaining the Bus/HOV 2+ lane in terms of both impacts on highway operation and possible adverse impacts to the local communities through which the Gowanus runs. Appropriate measures of effectiveness were identified, including incident measurements. Thanks to available electronic tolling, the study was able to examine the origins of HOV lane users. Based on its experience with the Gowanus lane as documented by the study, the New York State Department of Transportation (NYSDOT) decided to augment the Gowanus facility with a new Bus/HOV contraflow segment on the Prospect Expressway, which feeds the Gowanus on the approach to the BBT. This new facility is also being evaluated using the same measures of effectiveness identified for the Gowanus study.

Study data show that over one-third of the users had local (Brooklyn) origins. This is significant in that local critics of the Bus/HOV lane have argued that the facility only benefits "out of Borough" users. Because the Bus/HOV 2+ lane experiences substantial bus usage (approximately 200 in the peak hour), the number of individuals using the lane is considerable (over 11,000 in 1,200 vehicles); while peak hour person use in the remaining three general purpose lanes totaled only 5,000 in 4,000 vehicles. Based on peak hour calculations, over 165,000 person hours of travel were saved by the Bus/HOV 2+ lane.

Integrating Pricing Alternatives into the Planning and Project Development Processes

Patrick DeCorla-Souza, AICP, *Federal Highway Administration*

Abstract. Transportation agencies will need to fundamentally rethink the kinds of solutions that make sense in highly congested metropolitan areas. Three forces will cause a change in conventional thinking. First, we face a precipitous increase in congestion levels accompanying travel growth. Second, the public resists traditional major highway projects due to their community and environmental impacts. And third, many States face funding shortfalls. Value pricing alternatives can often accomplish transportation goals and objectives more efficiently and more effectively than conventional alternatives that exclude pricing, while generating net revenue surpluses to make funding of alternative modes financially feasible. Pricing solutions, although currently novel to members of the public and their elected and appointed governmental officials, will gain in acceptance as their real world performance becomes more widely understood.

This session will include four presenters who will discuss how value pricing can be incorporated into alternatives being considered during the planning and project development processes for major transportation improvements in metro areas, and how transportation performance and other impacts of pricing can be evaluated and compared to more traditional alternatives. The presenters will discuss, using their case studies, the analytical procedures and planning processes that were used to incorporate consideration of pricing alternatives and generate information for use by local decision-makers and the public. Proposed presenters, and proposed titles for their presentations are as follows:

- Bridget Wieghart, Portland Metro, "Integrating Value Pricing into the Planning Process in Portland, OR"
- Ken Buckeye, MN DOT, "Evaluating Regionwide Pricing Alternatives in the Twin Cities"
- Kim Kawada, SANDAG, "Planning for Bus Rapid Transit with Pricing on the I-15 Fastrak Lanes Extension"
- Bill Hayden, AZ DOT, "Planning for Value Lanes in Phoenix, AZ"

Planning for Value Lanes in Phoenix

Mark Schlappi, *Maricopa Association of Governments*

Abstract. The Arizona Department of Transportation (ADOT), in partnership with the Maricopa Association of Governments (MAG), contracted with Parsons Transportation Group to perform a Value Lane Study for the MAG Freeway System. In this context, Value Lanes represent a general concept by including High Occupancy Vehicle (HOV) lanes, as well as High Occupancy Toll (HOT) lanes. HOT lanes can best be described as new or existing HOV lanes that are opened to non-HOV (usually solo) drivers for a fee.

The purpose of the Value Lane Study was to provide information to policy makers on the MAG Regional Council and the State Transportation Board for use in updating the 1994 MAG HOV Plan and to assess the feasibility of converting HOV lanes to HOT lanes as well as constructing new HOT lanes. HOV and HOT lane approaches were evaluated, alternatives were then synthesized and the best alternatives were selected. Options were evaluated based on a wide range of factors. The financial, engineering and social support aspects of HOV and HOT lane concepts were evaluated and included in the recommendations.

Appraisal of social support was based on a public opinion survey. The examined usage and support for HOV. It also examined attitude towards HOT lanes. The financial and engineering aspects of the project were determined based on the travel demand forecasts made with the MAG regional transportation model. This model utilizes a nested logit mode choice program that explicitly estimated HOV and HOT trips, as well as transit trips.

The study recommended that 114 miles of HOV lanes be added to the MAG Regional Transportation Plan and that a HOT lane be considered as a demonstration project.

Converting HOV Lanes to HOT Lanes in Denver

Myron Swisher, P.E., *Colorado Department of Transportation*

Abstract. Colorado DOT has completed a study of the feasibility of conversion of existing HOV lanes on I-25 north out of downtown Denver to HOT lanes. The “minimum modifications” alternative was recommended for detailed study toward the implementation stage. This consists of conversion of only the existing HOV lanes without extension of the lanes. Subsequently, the Federal, State, and Local agencies involved all agreed that there is no fatal flaws in such a conversion and agreed that it should proceed into the NEPA documentation stage.

The FHWA Value Pricing Pilot Program was a funding partner in the original feasibility study. They have also committed \$1.7 million toward the design and implementation phases of the project and are considering CDOT’s application for an additional \$1.7 million. The NEPA documentation stage will begin in February, 2003. If approved, the construction phase could begin in the Fall of 2003.

This presentation will briefly track the interesting history of the project, describe the project in some detail, and offer our experience in successes and failures with regard to implementing similar projects.

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