Fully Incremental Model for Transit Ridership Forecasting: Seattle Experience

YOUSSEF DEHGHANI AND ROBERT HARVEY

Traditionally, comprehensive multimodal regional models have been developed to conduct travel forecasts for both highway and transit projects in major metropolitan areas throughout the United States. These models generally have failed to provide accurate, detailed forecasts for existing and proposed facilities, and unrealistic expectations can be placed on these comprehensive (super) regional models. Most of the large regional models in the United States are based on scanty transit ridership information compared with the amount of data available for the predominating automobile users. Transit-component validation of the models usually has been for aggregate market shares and volumes at a few screenlines. Under these circumstances, it is no wonder that comprehensive regional models fail to provide accurate ridership forecasts for specific transit lines. The transit ridership modeling for the Regional Transit Authority (RTA) in Seattle overcomes usual limitations by relying on comprehensive regional models only for regional growth, highway congestion, and regional model coefficients. RTA modeling is structured so that transit ridership results are based on observed origins and destinations of transit users, observed transit line volumes, and a realistic simulation of observed transit service characteristics. External changes, in demographics and in highway costs, are staged into the process in distinct phases before estimating the impacts of incremental changes in transit service. The RTA transit ridership model is simple and fully incremental. The modeling system was validated on the basis of base year comparisons with transit ridership counts, and on a 1992 to 1985 backward "forecast" of transit demand.

This paper describes a fully incremental transit ridership model designed for efficient and expedient evaluation of transit project planning and ridership forecasting analyses for the Regional Transit Authority (RTA) in Seattle. The RTA model is simple and uses incremental methods to estimate new shares both for primary modes (i.e., automobile and transit) and transit submodes (i.e., automobile and walk access). The incremental form is highly desirable because it is directly based on observed data that describe current conditions, instead of relying solely on models to estimate these conditions. The model can be used to conduct systemwide or corridor-level transit planning and patronage forecasting analyses. The RTA modeling system does not require any mode choice model calibration; it is an adjunct to the existing regional model with locally appropriate time and cost coefficients.

The incremental model is more realistic than the comprehensive regional synthetic models for transit ridership forecasting analysis because it

- Is based directly on observed instead of estimated baseline travel patterns of transit users;
- Allows concentration of effort on transit network analysis for studies whose primary goals are questions about alternative transit networks;
- Is more conducive to separate evaluation of changes in population and employment, highway congestion and cost, and transit services through the three stages of the forecasting process;
- Lends itself readily to intermediate evaluation by focusing on direct comparison instead of complete simulation of travel behavior; and
- Eliminates often laborious and time-consuming calibration of subchoice models because it does not require replication of base year travel patterns.

Y. Dehghani, Parsons Brinckerhoff, Inc., 999 Third Avenue, Suite 801, Seattle, Wash. 98104. R. Harvey, Regional Transit Authority, 821 Second Avenue, Seattle, Wash. 98104.

A model validation effort was conducted to address two points in time, 1985 and 1992. It included a validation of 1992 conditions as well as a backcast from 1992 to 1985.

The paper includes a discussion of the role of regionally based synthetic models and the history of staged incremental transit modeling at Seattle Metro. The RTA three-staged fully incremental ridership forecasting model is described, and results of the base year 1992 validation and 1985 backcast analysis are presented. Finally, some conclusions and incremental model limitations, as well as a few areas of future research, are offered.

ROLE OF REGIONALLY BASED SYNTHETIC MODELS

Traditionally, synthetic models have been used to predict multimodal travel demand on various highway and transit facilities. The conventional four-step synthetic method entails using separate models for (*a*) determination of total person trips in each zone, (*b*) distribution of total interzonal trips, (*c*) prediction of share of travel by each mode, and (*d*) estimation of demand volumes on transit and highway facilities. Supplementary subarea models and procedures are usually used to generate detailed link-specific travel demand forecasts. The subarea (synthetic) models use incremental methods to the extent that they directly use available base year traffic counts in their application phases.

In the Puget Sound region, there are about 15 separate but interdependent transportation models. Only one, maintained by the Puget Sound Regional Council (PSRC), is a regional synthetic model, complete with feedback loops on land use. The remaining subarea models provide focused analysis on local transportation supply issues, primarily those related to street and highway capacity.

Unrealistic expectations are often placed on comprehensive (super) regional models. At its best performance, a regional model can be expected to generate reasonably reliable travel forecasts only along supercorridors and among very large districts. The inability of regional models to produce detailed project-specific travel demand forecasts probably has been a major factor in the proliferation of subarea models.

Previous research findings indicate that generation of reasonable land use forecasts is possible only at a superdistrict level (*1*). Consequently, breaking a geographic area into several smaller districts does not necessarily lead to a more accurate regional model. Past research (*2,3*) also indicates that the larger (level) district regional models will facilitate efficient integration of appropriate algorithms to allow full interactions and equilibrium among land use, travel time, and cost variables, as well as resulting travel demand.

The practical function of superregional models appears to be as a base for input to more focused application models, instead of for direct application to transportation studies. An auxiliary function of the superregional models has been to systematize a regional information data base, including land use and demographic data and forecasts. Direct application of the models to transportation studies increasingly has been limited to "big picture" questions on regional air quality, regional travel demand, or long-term land use visions. Because of the limitations of supermodels, the need to develop simple models that are operationally more efficient and sensitive to project settings—as well as able to produce more realistic detailed travel demand forecasts on both transit and highway facilities—has become more evident than ever.

HISTORY OF STAGED INCREMENTAL TRANSIT MODEL AT SEATTLE METRO

Work by Brand and Benham (*4*) led, in 1985, to the Metro staff's consideration of a "quick-responsive incremental travel demand forecasting method" based on the concept of staged forecasting analysis. In 1986 Metro installed "logit mode-choice equations for pivot-point analysis" on EMME/2 software (R. Harvey, unpublished data, 1986). These equations were translated from descriptions by Ben-Akiva and Atherton (*5*), Koppleman (*6*), Nickesen et al. (*7*), and many others.

In 1988, Metro clarified the relationship between its incremental transit forecasting model and the regional model at PSRC (R. Harvey, unpublished data, 1988). At that time, the method included (*a*) four distinct stages for ridership forecasting analysis, (*b*) an incremental mode-of-access component, (*c*) the use of regional person trip tables to represent growth (in lieu of a Fratar-type calculation), and (*d*) direct use of the regional model coefficients on travel time and cost variables (R. Harvey, unpublished data, 1989).

In 1991 a team of Metro staff and Parsons Brinckerhoff consultants updated the process for the Regional Transit Project, resulting in a *Travel Forecasting Methodology Report* (*8*) in October 1991. Changes included (*a*) synthetic access-mode and automobile-occupancy submodels with borrowed and adjusted coefficients, (*b*) return to a Fratar-type matrix balancing for growth, (*c*) consolidation of cost and highway time impacts in the staged forecasting analysis, (*d*) an increase in the number of zones, and (*e*) more emphasis on trip purpose in the model structure. The 1991 version of the RTA model was a combination of incremental approaches previously used by Seattle Metro and J. M. Ryan of Parsons Brinckerhoff, Inc. Before the Seattle application (*8*), Ryan had used incremental methods for ridership forecasting analysis in a number of cities in the United States, including San Francisco (*9*), Baltimore (*10*), and Honolulu (*11*), for evaluation of major transit investments.

In 1993, the process was again refined, reflecting a renewed commitment to integration with the regional model. Transit operators completed a new set of comprehensive ridership surveys and counts, providing a new base for the model. Refinements included (*a*) use of regional model coefficients for consistency, (*b*) return to regional trip tables for consideration of regional growth, (*c*) addition of a fully integrated incremental model to represent transit and automobile submodes, and (*d*) further refinement of the zone structure. An updated *Travel Forecasting Methodology Report* (*12*) summarizing these changes and the new transit surveys was published in November 1993.

Presently, there are well-established markets for park-and-ride and group ride activities in the Seattle area. Potential difficulties with the use of an incremental transit access component, usually considered to be related to zero or 100 percent shares in the cells, are not problematic with the RTA model application. The following factors allow the RTA model to avoid the problem:

- There are more than 50 park-and-ride lots within the RTA area.
- The automobile-access definition used from the surveys included all automobile access to transit.
- There is extensive peak-period coverage with local bus service throughout the RTA area. Almost all park-and-ride service is provided by groups of separate local routes that come together at lots before beginning the express portion of the trip.
- Mode-of-access shares were calculated from the aggregation of survey data to larger districts, especially at the attraction ends.
- A boundary has been used (i.e., 10 to 90 percent) for calculation of the access shares. The precaution is both practical and reasonable because of the four considerations just noted.

The reasons for changing the transit access submodel to an incremental form again in 1993 related primarily to difficulties encountered in trying to match base access shares to important markets, such as downtown Seattle, with a synthetic component (*8*). The availability of a new set of access-mode share data from the 1992 surveys suggested that an incremental approach would be preferable.

STAGED INCREMENTAL FORECASTING ANALYSIS

Underlying methods and assumptions used in the 1993 RTA three-stage fully incremental ridership forecasting model are now described.

Incremental Logit Model Equations

The incremental form of the logit model is derived from the standard logit formulation. Ben-Akiva and Lerman state:

> . . . using elasticities is one way to predict changes due to modifications in the independent variables. For the linear-in-parameters multinomial logit model there is a convenient form known as the *incremental logit* which can be used to predict changes in behavior on the basis of the *existing choice probabilities of the alternatives and changes in variables* that obviates the need to use the full set of independent variables to calculate the new choice probabilities. (*13*)

Mode-specific constants in a synthetic model theoretically represent the effects of unmeasurable attributes and usually capture more than two-thirds of explanatory power in logit models (*14,15*). In actuality, these constants are quite large, and they compensate for all types of errors in synthetic models, even network coding idiosyncrasies. They are used as overall adjustment factors to move the model results close to targeted regional totals; they typically range as high as 50 to 150 min. of equivalent in-vehicle time. Without these constants, synthetic models could never replicate even the regional totals for a base year. The mode-specific constants fall out of the computations in the incremental logit model.

Recursive Logit Model

The recursive "nested" form of the logit model is less restrictive; therefore, it is more attractive than the simultaneous structure to travel demand practitioners. However, there is no convincing statistical evidence or professional consensus on using a particular recursive (nesting) structure.

In the absence of a theoretically sound behavioral theory to describe mode choice formation and a consensus on the form of a recursive logit model, the RTA uses an implicit recursive structure only, because of computational convenience in using the incremental logit model to estimate new shares for both the primary and subchoice modes. The RTA model also uses a coefficient of 1.0 for the LogSum variable, which is consistent with the PSRC simultaneous logit model forms.

For an incremental logit model application, primary modes (i.e., transit and automobile) are represented by subchoices. For the transit mode, the subchoice is between access to transit by walking or by automobile. For the automobile mode, the subchoice is between single and multiple occupancy for commute trips. For noncommute trips, all automobile submodes are combined into a single automobile mode.

LogSum Variable

The natural logarithm of the denominator of the standard logit model is a single "inclusive" index, I_m, *(16)*, indicating the desirability of main mode *m,* taking into account the attributes of access modes. This index is often called LogSum and calculated from

$$\text{LogSum} = \log \{\text{SUM}_j^m [\exp(V_j)]\}$$

where V_j is the utility of mode i in choice set m (j = 1, 2, 3, . . . , i, . . ., m) and contains measurable components of transportation systems, such as travel time and cost as well as socioeconomic attributes of trip makers.

Derivation of Changes in LogSum Variable

Contrary to a synthetic subchoice model, new shares for submodes are computed using incremental methods. That requires derivation of an appropriate formula to compute the difference in the values of the LogSum variable for submodes (e.g., DIFF LogSum^t for the mode of access). The derivation process starts by using the definition of difference in the LogSum values and ends up with a simple formula, as follows:

$$\text{DIFF LogSum}^m = \ln \{\text{Sum}_i^n[S_i * \exp(\text{DIFF } V_i)]\} \quad (1)$$

where

DIFF LogSum^m = difference (future − base year) in LogSum term for mode m,
V_i = utility of submode i (e.g., walk or drive access attributes) within subchoice n (i.e., automobile or transit),
S_i = base year observed share of using submode i (e.g., walk or drive access), and
DIFF V_i = difference (future − base year) in the utility (e.g., travel time) of submode i.

Model Specification and Coefficients

The RTA model includes

- Transit travel time and cost (i.e., in and out-of-vehicle times and transit fare) variables in the utilities of the transit submodes, walk and drive access; and
- Automobile travel time and cost (i.e., parking and automobile operating) variables in the utilities of the automobile submodes.

The cost variable is normalized with respect to zonal median income. This composite variable is constructed by dividing the automobile cost components (i.e., sum of automobile operating, parking, and ownership costs) and transit fares by the ratio of zonal median income over the base year regional median income. The PSRC mode choice model coefficients are used in the incremental mode choice models.

Base Mode Shares

Application of the incremental logit model requires a reasonable estimate of existing shares for each alternative mode. The census journey-to-work data provide an excellent source of automobile, carpool, and transit shares for commute trips. Even with those data, however, there are many zone-to-zone interchanges with no reported shares. Base mode shares, therefore, are computed by aggregating shares to 26 summary districts at the work ends only. The shares at home ends are calculated at a 219-FAZ (PSRC forecasting analysis zones) level.

For derivation of the base year park-and-ride shares, a procedure similar to that just mentioned is used to aggregate the shares. Specifically, base year park-and-ride shares are calculated at 26-district-to-219-FAZ interchanges using the transit on-board origin and destination data.

Surveys Conducted in 1985 and 1992

The 1985 survey conducted by Seattle Metro and the 1992 surveys conducted by the four transit operators (Metropolitan King County, Pierce County, Everett Transit, and Community Transit) provided a complete cross section of representative transit trips for two separate years. The 1985 survey was limited to only one county (King); the 1992 surveys covered the three-county RTA area shown in Figure 1 (see Table 1).

Transit operators also provided detailed ridership counts by route and time of day, which were the basis for expanding the surveys to 100 percent of the transit travel.

Time of Day and Trip Type Hierarchy

For the project planning studies, the RTA assumes that most questions to be addressed by the modeling effort would require tests of alternate transit service instead of alternate external environments. Variables affecting ridership are more related to time of day than to trip purpose for these questions. For example, both fares and service

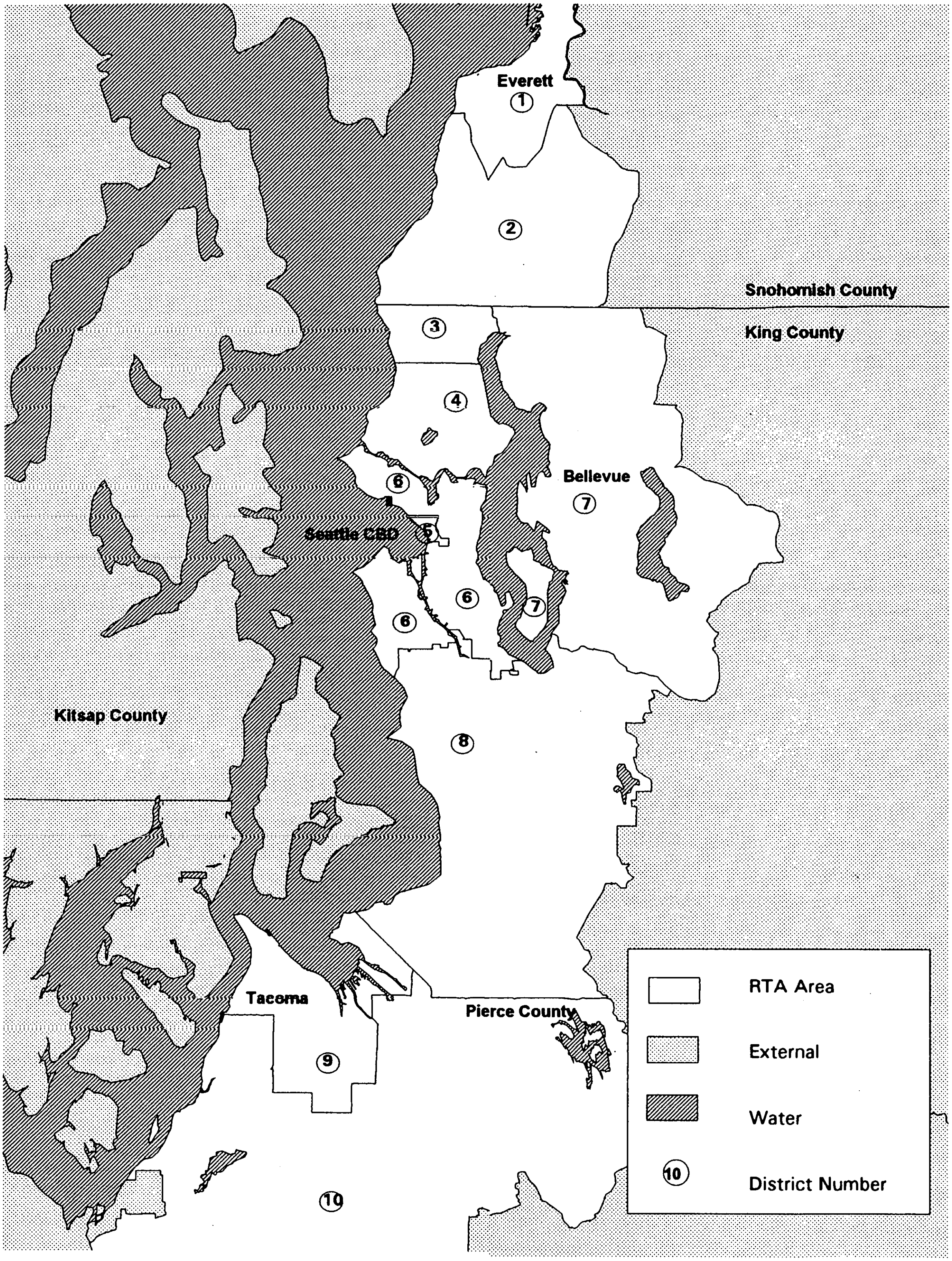

FIGURE 1 Ten districts within the RTA area.

TABLE 1 On-Board Transit Surveys

	King County	Seattle CBD	Pierce County	Pierce Seattle Express	Everett Transit	Community Transit
Month Conducted	May-92	Feb-93	Sep-92	Apr-92	Nov-92	Nov-92
Responsible Agency	Metro	Metro	Pierce Transit	Pierce Transit	Everett Transit	Community Transit
Approximate Response Rate	40%	20%	30%	60%	50%	50%
Percent of 3-County Ridership	75%	8%	8%	1%	2%	6%

vary by time of day, not by trip purpose. In fact, service variability by time of day is quite extreme in the Seattle area. The RTA model simulates afternoon peak and off-peak transit travel patterns.

Rider response to on-board survey questions on trip purpose is not as strictly controllable as are travel diary surveys or interview-based surveys. Therefore, the RTA model uses a simple categorization of trips, "commute" versus "noncommute."

RTA Staged Forecasting Analysis

Stage 1: Changes in Demographics

The RTA model uses PSRC trip tables to change surveyed transit demand from a base year to a forecast year. Because there are many mismatches due to the occurrence of zeros within any two trip tables, some aggregation is necessary to ensure reasonable application of cell-to-cell growth factors. The RTA model calculates factors at the level of 219-FAZs. The RTA modeling effort will retain the Fratar method as a backup to using regional trips from the PSRC trip distribution model. The calculation is

$$\text{Stg1Trn} = \text{SurvTrn} \times \frac{\text{Trips}^f}{\text{Trips}^b}$$

where

Stg1Trn = Stage 1 transit trip forecasts (737 × 737 zones),
SurvTrn = base year surveyed transit trips (737 × 737 zones),
Trips^f = forecast-year PSRC travel demand (219 × 219 FAZs), and
Trips^b = base-year PSRC travel demand (219 × 219 FAZs).

The results of the Stage 1 analysis are the transit trips for a future year assuming nothing changes but population and employment. Secondary impacts of growth on transit demand, such as increased highway congestion, are not accounted for in Stage 1.

Stage 2: Changes in Highway Congestion and Cost

Stage 2 considers influences on mode choice due to changes in highway congestion, automobile costs (including parking costs), transit fares, and income.

In all of the ridership analysis done in the Puget Sound region, transit fares have been held constant across alternative transit networks. Should that approach change, it would be advantageous to shift consideration of transit fares to Stage 3, where the fare policy could vary with each transit network.

PSRC is responsible for all regional highway modeling. RTA patronage forecasts use PSRC estimates of highway travel times. The times are tabulated in the form of 219 × 219 FAZ-to-FAZ matrices for each highway network. When a transit alternative significantly affects the highway system (e.g., taking of freeway lanes for transit facilities), additional PSRC future highway networks and congestion analysis are required.

Stage 2 transit trip forecasts are calculated using the following incremental logit equation:

$$\text{Stg2Trn} = \frac{\text{Stg1Trn}}{S_t + (1 - S_t) * [\exp(B * \text{DIFF LogSum}^a)]}$$

where

Stg2Trn = Stage 2 transit trip forecasts,
Stg1Trn = Stage 1 transit trip forecasts,
S_t = observed transit shares from census data for base year,
B = LogSum variable coefficient (equal to 1.0) for the automobile subchoice, and
DIFF LogSum^a = difference in the LogSum values due to changes in highway congestion and costs (future − base year) [census data (for the baseline share), highway skims and costs, and fares are used in Equation 1 to estimate DIFF LogSum^a representing drive alone and group ride submodes].

Stage 2 transit share forecasts (Stg2Shr) are calculated as follows:

$$\text{Stg2Shr} = \frac{\text{Stg2Trn} * S_t}{\text{Stg1Trn}}$$

Results of Stage 2 analysis are the transit trips for a future year, having accounted for factors external to the transit service itself. The results serve as a platform for analysis of ridership on alternative transit networks.

In most project planning ridership forecasting, Stages 1 and 2 need not be calculated as often as Stage 3. Only when a transit alternative is presumed to have a strong effect on land use or the regional highway network, for example, would the entire process have to be cycled through. Guidelines published by FTA (*17*) discourage such cycling in the evaluation of transit investments.

Stage 3: Changes in Transit Service

In the third and final stage of the forecasting analysis, incremental changes in the transit level of service are taken into consideration. The change is reflected in resulting relative values of the LogSum^t variable using the base year and future transit networks. Stage 3 transit ridership forecasts, Stg3Trn, are calculated as follows:

$$\text{Stg3Trn} = \frac{\text{Stg2Trn} * [\exp(B * \text{DIFF LogSum}^t)]}{\text{Stg2Shr} * [\exp(B * \text{DIFF LogSum}^t)] + (1 - \text{Stg2Shr})}$$

where

B = Logsum variable coefficient (equal to 1.0) for the transit subchoice, and

DIFF LogSum^t = difference in LogSum values due to changes in transit level of services (future − base year). Base year observed shares for park-and-ride and changes in transit level of services are used in Equation 1 to estimate DIFF LogSum^t representing walk- and automobile-access submodes.

RTA ridership analysis involves preparation of summary information on the three-stage incremental forecasting process for each alternative plan. Sample trip ends for p.m. (noon-to-midnight) origin districts (see Figure 1 for the district definition) are indicated in Table 2. Information presented in Table 2 facilitates separate examinations of the potential impacts of incremental change in each variable at each stage of the ridership forecasting analysis.

MODEL VALIDATION AND BACKCAST RESULTS

RTA model validation analyses were conducted for both the base year 1992 and the 1985 backcast.

Route-Level Validation Results

Figure 2 shows the model's replication of route-level boardings for 1992. The surveyed and expanded transit trips were assigned to the model network to validate boardings and transfer penalties. Figure 2 shows a regression of total boardings on 342 lines against the automated passenger counter (APC) boardings on these lines. The R^2 of 0.91 and standard deviation of 369 daily boardings indicate a remarkably close match.

No boarding counts by route are available for 1985 because the APC system was not operational at that time. Boardings for Pierce County and Snohomish County routes are from driver counts.

Observed versus Estimated 1985 Backcast Results

Table 3 compares observed and estimated 1985 transit trips. A comparative analysis is possible for trips within King County (excluding intra–central business distinct) because of the availability of observed 1985 transit trips from the King County 1985 transit survey. No comparison can be made for other counties because no survey was conducted in 1985 for those transit markets. Overall, the RTA

TABLE 2 Sample Build-Up/Down Analysis: 1992 to 1985 p.m. Daily Transit Trips by p.m. Origins

PM Origins	1992 Observed Trips	1985 Stage 1 Trips	1985 Stage 2 Trips	1985 Stage 3 Trips	Stage 3 % Change From 1992
1 Everett	4,060	3,160	3,260	3,880	-4.4%
2 SW Snohomish County	1,620	1,160	1,390	1,410	-13.0%
3 Shoreline	920	830	900	930	1.1%
4 North Seattle	21,370	20,120	18,880	18,470	-13.6%
5 Seattle CBD	53,270	45,010	46,620	46,700	-12.3%
6 South Seattle	25,470	25,000	26,880	27,490	7.9%
7 Eastside	4,840	3,350	3,640	3,770	-22.1%
8 South King County	6,560	5,620	6,270	6,360	-3.0%
9 Tacoma	7,570	7,000	7,880	7,680	1.5%
10 Pierce County	2,150	1,850	2,190	2,170	0.9%
Total (Noon-to-Midnight)	**127,830**	**113,100**	**117,910**	**118,860**	**-7.0%**
% Change Relative to 1992 Observed Trips	0.0%	-11.5%	-7.8%	-7.0%	
% Change Relative to Previous Step in Build-Up/Down Analysis	----	-11.5%	4.3%	0.8%	

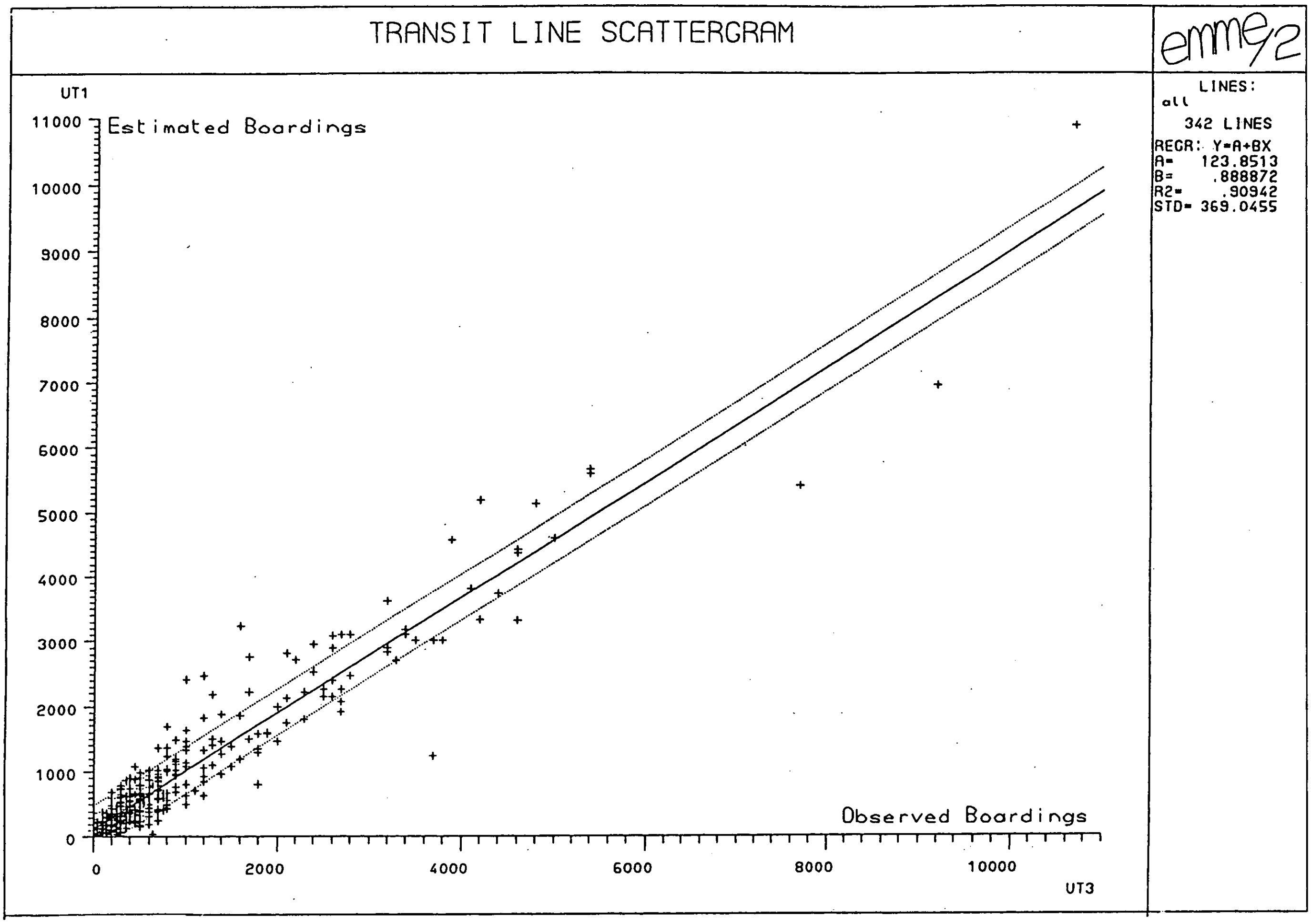

FIGURE 2 Daily transit line boarding comparison for 1992.

model has produced accurate 1985 backcasts for about three-fourths of the markets with over 1,500 daily transit trips (at least in King County). Those results are based on using the EMME/2 matrix balancing method to generate Stage 1 forecasts. Use of regional trip distribution estimates from the PSRC model resulted in worse 1985 backcasts for most markets (*12*). Comparative analyses of the EMME/2 matrix balancing (Fratar) method and trip distribution gravity model will be the subject of a future paper by the authors.

Results from Highlighted Changes in Transit Service, 1992 to 1985

In evaluating RTA model performance, one useful criterion is whether the model replicated ridership response to measurable changes in the transit systems between 1992 and 1985. The existing fully incremental RTA model has been responsive to measurable changes in transit systems between 1992 and the 1985 backcast year. There have been only a few changes in transit service between 1985 and 1992. Distinct and measurable changes in transit service between 1985 and 1992 include

- Change in park-and-ride express bus services from Snohomish County to Seattle,
- Change in park-and-ride express bus services from Pierce County to Seattle,
- Opening of the Downtown Seattle Transit Tunnel, and
- Introduction of the U-PASS Program in the University of Washington district.

The U-PASS program is a transit pass that makes transit virtually free for University of Washington students and some staff. These changes should have caused an increase in 1992 ridership relative to 1985 within these markets. The RTA model has responded correctly to the changes, as reflected in the resulting 1985 transit trip estimates (see Table 4). In summary, the RTA model has estimated

- 23 percent fewer p.m. peak automobile-access transit trips between downtown Seattle and Snohomish County in 1985;
- 36 percent fewer p.m. peak automobile-access transit trips between downtown Seattle and Pierce County in 1985; and
- 13 percent fewer intra–Seattle central business district, off-peak, noncommute trips in 1985.

Additional results pertaining to changes in intercounty park-and-ride express service during the 7-year interval are summarized in Table 5.

TABLE 3 Comparative Analysis of 1985 Estimated and Observed Daily Transit Trips by Origin and Destination (King County Districts Only)

Origin District		Destination District 1	2	3	4	5	6
1 Shoreline	Estimated	201					
	Observed	264					
2 North Seattle	Estimated	933	16,449				
	Observed	**1,052**	**14,125**				
3 Seattle CBD	Estimated	1,675	10,923	n/a			
	Observed	**1,669**	**11,667**	**n/a**			
4 South Seattle	Estimated	551	10,897	19,265	25,415		
	Observed	**733**	**9,472**	**21,632**	**24,554**		
5 Eastside	Estimated	194	1,759	4,469	2,070	2,511	
	Observed	**175**	**2,074**	**5,211**	**1,734**	**3,346**	
6 South King County	Estimated	95	1,153	4,980	3,352	772	6,028
	Observed	**164**	**1,239**	**5,223**	**3,500**	**753**	**6,869**

* Numbers on the observed rows represent 1985 transit trips from Metro King County on-board Survey.

TABLE 4 Model Performance in Response to Highlighted Transit Changes Between 1992 and 1985

Highlighted Change	Transit Trip Type	To	1992 Observed Trips	1985 Estimated Trips	1985 % Change From 1992	1985 Actual Change
Increase in Cross-County Express Bus Service to New Park-and-Ride	PM Peak Park-and-Ride	Snohomish County	2,500	1,900	-24%	-30%
	PM Peak Park-and-Ride	Pierce County	1,000	600	-40%	-50%
Opening of Downtown Transit Tunnel	Off-Peak Non Commute	Seattle CBD (Intra-Trips)	8,900	7,720	-13%	Not Available

TABLE 5 Model Performance in Response to Intercounty Park-and-Ride Express Service (Daily Transit Volumes)

Screenline Location	1992 Observed	1992 Estimated	1985 Observed	1985 Estimated
Pierce County Line:	2,600	2,700	1,000	1,000
Snohomish County Line:	8,700	9,000	5,800	5,600

CONCLUSIONS AND AREAS OF FUTURE RESEARCH

The incremental model presented in this paper is simple and can be easily applied to other projects for a more efficient and accurate transit ridership forecasting analysis. Implementation of the RTA fully incremental model became possible because of the availability of new surveys covering well-established markets of all transit riders, including park-and-ride users in the Seattle area. The integration of incremental subchoice models should be a noticeable improvement compared with traditional synthetic methods. Initial results from the validation analyses have clearly demonstrated responsiveness of the RTA model to changes in transit service, although limited, between 1985 and 1992.

The incremental RTA transit model is more efficient for transit planning analysis, because it

- Is simple and is directly based on observed travel, not estimated travel;
- Is an adjunct to the existing regional model and requires no model calibration;
- Has been responsive to highlighted changes in transit service from 1992 to 1985;
- Has reproduced observed travel patterns for park-and-ride transit users;
- Concentrates efforts on transit network analysis for studies whose primary questions are about alternative transit networks;
- Highlights error sources effectively whether in networks or in trip data; and
- Is a cost-effective and transparent staged forecasting process.

Incremental Model Limitations

The incremental model also has some limitations, because it

- Requires observed baseline travel pattern of transit trips;
- Is applicable only to areas with relatively good existing transit coverage;
- Would require a synthetic submodel for areas without well-established park-and-ride markets or transit in general;
- Requires availability of a regional model for nontransit input data and for interfaces with highway analysis;
- Is not well-suited for comprehensive analysis of major structural changes, such as land use visions involving feedback loops to transportation investments; and
- Requires good coordination with regional modeling staff and local traffic modeling staff for evaluation of transit improvement impacts on highway facilities.

Areas of Future Research

Presently, the incremental method is not useful for long-range multimodal corridor studies, comparing simultaneous transit and highway improvement strategies. Research should be directed toward developing methods such as the gradient approach suggested by Spiess (*18*) for estimation of base year origin to destination trip tables, possibly for all modes, from the existing actual counts of passengers and vehicular traffic. Such counts are usually collected by transit operators, cities, counties, and state transportation departments. Availability of base year trip tables for both transit and automobile modes will extend application of the incremental method not only to traffic forecasting but also to multimodal modeling analyses. Use of incremental models will not only simplify the existing travel demand modeling practices but also greatly enhance efficient generation of detailed project- and subarea-specific travel demand forecasts.

Currently, the incremental method depends on trip-based definition instead of activity-based definition. That limitation can be rectified by incorporating pertinent findings from new research into existing regional synthetic models before incremental methods are applied.

Finally, research also should be directed toward either limiting or eliminating conventional zone definition in transportation modeling and forecasting processes. Trips or activities should be geocoded to their actual surveyed household and destination locations rather than using traditional origin and destination zones. That concept will allow the transformation of modeling from a matrix-calculation environment to the calculation of incremental equations directly on the survey records, including use of trip-specific, as opposed to zone-specific, data for the level-of-service attributes. Limited experiments by the authors on a no-zone concept in incremental transit modeling have been encouraging but require additional research on representation of access-mode choices.

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