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Multimodal Logit Travel-Demand Model for Small and Medium-Sized Urban Areas

MICHAEL J. CYNECKI, SNEHAMAY KHASNABIS, AND MARK A. FLAK

The development and application of a one-step modal-split process that uses the logit approach and is oriented toward the needs and attributes of small and medium-sized urban areas are described. The essence of this study lies in the tailoring of commonly available aggregate (zonal) data for use in the disaggregate-based logit model, which is currently included in the Urban Transportation Planning System planning package. The development of work-trip and non-work-trip models is presented separately for the Flint urban area in Michigan. Each model studied the following five modes: (a) automobile, drive alone; (b) automobile, one passenger; (c) automobile, two passengers; (d) automobile, three or more passengers; and (e) transit, bus service. The results of the study indicate that the development of multimodal logit modal-split models is feasible by using aggregate data, and that the potential of applying this approach in other urban areas is quite high, although further calibration and validation efforts are needed before a more widespread application is practiced. The study also shows that, unlike traditional modal-split (diversion-curve-type) models, the resource requirements for these models are nominal and thus can be used for transportation planning purposes in small and medium-sized urban areas. The model is also sensitive to changes in transportation system attributes as well as in tripmaker characteristics and can be applied for testing air quality, energy, and other impacts of transportation strategies typical of smaller urban areas.

The increasing concern about traffic congestion, air pollution, and energy shortages in recent years has caused most urban areas in the United States to promote public transportation and ridesharing programs. Historically, the emphasis on such transit-related activities has been directed toward large urban areas. It is only during the past few years that small and medium-sized urban areas have been receiving significant attention on transit, ridesharing, and other transportation system management (TSM) programs.

Travel-demand forecasting constitutes the most critical element of the urban transportation planning process. The traditional approach to transit-demand analysis has been criticized as being oriented toward larger cities and being insensitive to the needs and attributes of small and medium-sized urban areas (1). Typically, travel-demand models are cross sectional in nature, as these are developed on the basis of data for a single time period (2,3). Empirical relations are developed from observed data on travel, land use, and demographic characteristics of the area that are used to forecast future travel desires. The data needs for these models are generally very high, and smaller urban areas are hard-pressed to commit the resources necessary for the collection and retrieval of such a data base. The process of allocating travel among a number of competing modes, commonly known as the modal-split process, has posed particularly significant problems to these small areas.

The recent emphasis on different types of ridesharing programs presents further problems to these smaller areas. Most of the available demand models can allocate travel between two modes at a time as opposed to many modes at the same time. When a multiple number of modes are involved, the analyst must take recourse to a submodal-split process that successively allocates travel between two modes at each step. This process of successive allocation can get complicated due to the need to calibrate the model at each step and to trace backward whenever the model output might not provide an acceptable match to observed data.

Obviously, any modeling error committed at a given step would be propagated to all successive steps by this submodal-split process. Thus, the overall reliability of such a model is likely to be questionable when a multiple number of modes are involved. This process becomes lengthy, involved, and costly, which makes it somewhat inappropriate for application to smaller areas.

The above-mentioned procedure, despite the complexities involved, has been successfully used in multimodal travel-demand forecasting for large urban areas (2). There is, however, a need to develop a simpler procedure for smaller urban areas, where resources are constrained and where transit options are quite limited and bus travel is the only feasible mode. This need becomes more evident when one considers the current emphasis on developing plans that involve different levels of automobile occupancy. For example, How does the transportation planner assess air quality, energy, and other impacts of a shift in automobile travel from a low occupancy level to higher occupancy level? What are the overall effects of such a shift in the total vehicle miles of travel generated in a medium-sized urban area?

The purpose of this paper is to describe the development and application of a one-step modal-split process designed specifically for small and medium-sized urban areas. This paper is the result of a study sponsored by the Michigan Department of Transportation (MDOT) that had the objective of developing a procedure for testing the demand consequences, air quality, and energy impact of alternate transportation strategies for medium-sized urban areas (4). The model developed with this study is multimodal in nature and does not require the lengthy step-by-step process of branching and submodal split. Further, the model is oriented toward the data base commonly available for small and medium-sized urban areas and is responsive to the needs of smaller urban areas. The model is developed around the Urban Transportation Planning System (UTPS) software framework by using the logit approach and lends itself to convenient calibration through the selective use of variables that are initially created in a calibration file. Unlike traditional modal-split (diversion-curve-type) models, the resource requirements for these models are nominal, and the models can be fine-tuned with minimal effort. Last, the model is sensitive to changes in transportation system attributes, as well as in tripmaker characteristics, and can be applied for testing air quality, energy, and other impacts of transportation strategies typical of smaller urban areas.

LOGIT MODEL

A logit model incorporates modal-choice decisions through the use of explanatory variables in a set of mathematical formulations. Probabilistic equations are developed to reflect characteristics based on the relative attractiveness of the candidate modes, as expressed below (5):

$$P(i-j/m) = \exp[-U(i-j/m)] / \sum_{m=1}^{N} \exp[-U(i-j/m)] \quad (1)$$

where $P(i - j/m)$ is the proportion of total person trips from zone i to zone j by using mode m, and N is the total number of travel modes (m). The modes are numbered consecutively 1 through N. Further, $U(i - j/m)$ is the utility or disutility value of a trip from i to j by using mode m, as described below:

$$U(i-j/m) = F_c(i-j/m) + F_t(i-j/m) + F_s(i-j/m) \quad (2)$$

where

- $F_c(i - j/m)$ = function of the out-of-pocket cost in making the trip from i to j by mode m,
- $F_t(i - j/m)$ = function of the travel time in making the trip from i to j by mode m, and
- $F_s(i - j/m)$ = function of the socioeconomic characteristics of the tripmaker or land use characteristics associated with trips from i to j by mode m.

In addition, the following must hold true:

$$\sum_{m=1}^{N} P(i-j/m) = 1.00 \quad (3)$$

Each of the three utility or disutility functions (F_c, F_t, and F_s) can be developed as a linear or nonlinear combination of independent variables. A linear combination of the following form was used in this study:

$$F(i-j/m) = (\alpha_1 X_1 + \alpha_2 X_2 + \ldots + \alpha_n X_n) \quad (4)$$

where

- $F(i - j/m)$ = impedance function (time, cost, distance, etc.) for trips from i to j by using mode m,
- X_i = individual elements within the impedance function (e.g., in-vehicle time, waiting time, out-of-pocket cost, parking cost, etc.), and
- α_i = coefficients to be derived as a part of the model calibration.

Model Attributes

The logit model described in this paper has the attributes described below:

1. Aggregate data base: The most important feature of the modeling process described in this paper is the use of data aggregated at the zonal level. Logit models are typically developed for household-level analysis to reflect individual tripmaker decisions; however, the time and cost involved in the use of disaggregate data have often precluded their use. A major emphasis in this modeling process was to investigate the traditional approach of using zonal data in a logit model without any significant loss of accuracy.
2. Multimodal: Logit models can apportion trips among several modes in a single step. This feature lends the model quite well to analyzing different levels of automobile occupancy and public transit modes as individual modes.
3. Multinomial: Logit models can use several independent variables to describe tripmaking characteristics. This feature increases the model's flexibility to include several factors that may affect modal-choice decisions.
4. Existing software: The models were calibrated by using the ULOGIT computer program from the UTPS modeling package (5). Other UTPS modules were also used in this study.
5. Flexibility of calibration: Once a model formulation is developed, the ULOGIT program can be used to selectively add, delete, or modify variables for calibration purposes. The ULOGIT module provides a series of statistical outputs to evaluate the model. This approach allows considerable flexibility in testing several different model formulations and results in a more thorough search for the best model.

Modeling Process

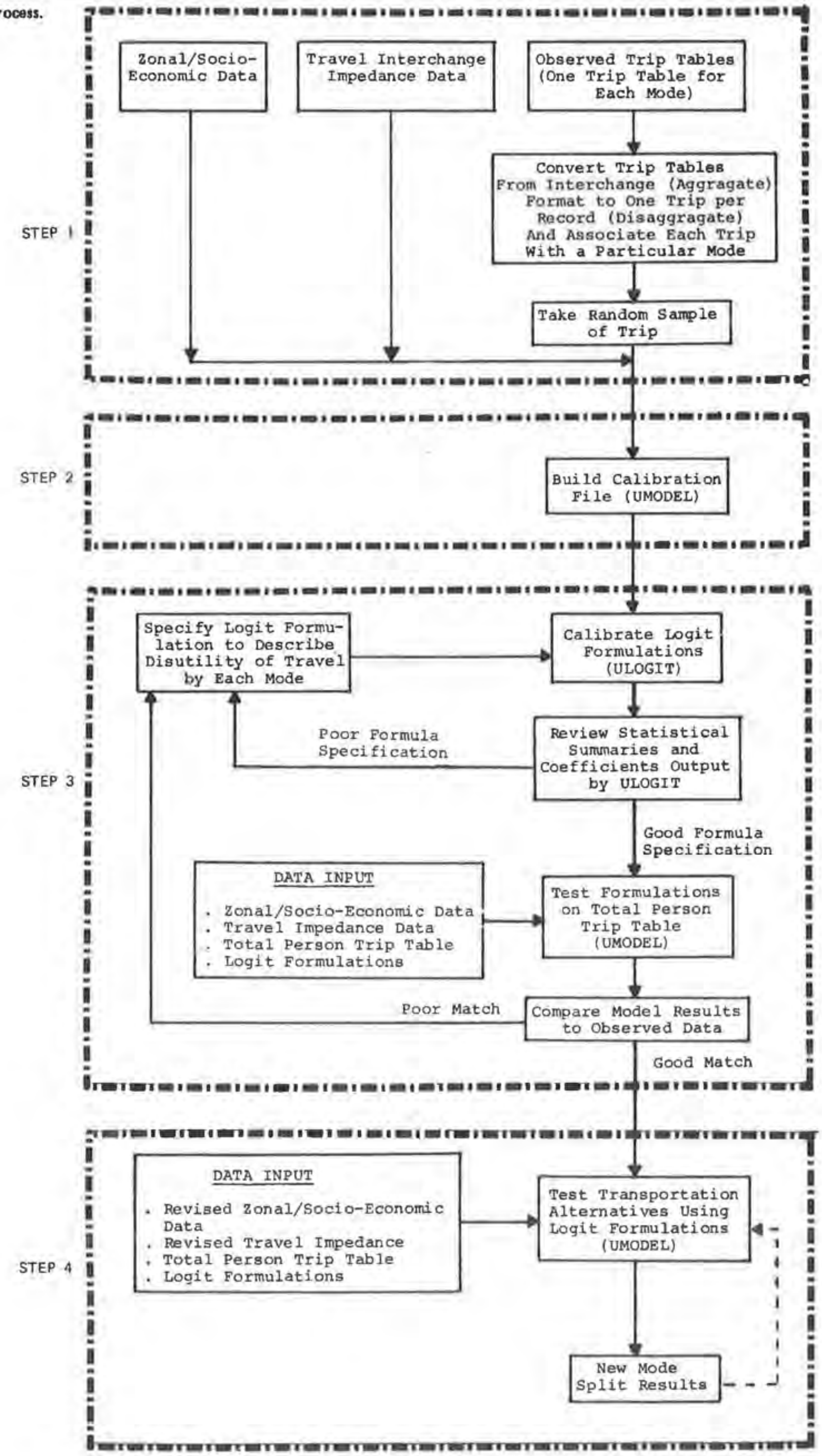
The process to develop and calibrate the logit modal-split models as described in this paper is shown in Figure 1. The process contains four main steps. The first step is to prepare the data for the calibration file. The data used include observed modal trip tables, trip interchange impedance data, and zonal socioeconomic and land use data.

When working with a large data base, it is preferable to calibrate the model by using a sample of trip data in order to reduce computing costs. The sampled trip records should be selected at random but should still maintain the same proportion of trips among different modes.

The second step involves developing a calibration file from a random sample of observed trips through the use of the UTPS program UMODEL. This file provides a specification of variable names, units, and all possible variables (mode, travel time and cost, socioeconomic data, etc.) that may be used in the ULOGIT computer runs.

The calibration file consists of a matrix in which the rows correspond to observed trip records (1 trip/record) and the columns correspond to trip information (variables). The aggregated data are converted into a disaggregated form in the calibration file (6). However, the data for each trip represent a zonal average of variables such as income, land use, etc. The dependent variable in the calibration file relates to the mode of travel and assumes a binary form. Each trip in the file is asso-

Figure 1. Flowchart of logit modeling process.



ciated with one and only one mode, and the mode is identified by a 0 or 1 in the appropriate column.

In step three, the ULOGIT module is used to develop coefficients for the disutility equations. The input to the ULOGIT program is the calibration file (developed in step 2) and a set of explanatory variables for each disutility equation. The variables should be related to the tripmaker's decision to use this particular mode. The output of the ULOGIT calibration program is a value for each coefficient that best fits the model formulation to the observed trip data, along with a set of statistics that are used to evaluate each model.

Once an acceptable model is calibrated to a sufficient degree of accuracy, it can be employed to test various transit options or TSM strategies (step 4). The application of a calibrated model to a new design year, revised economic situations, or other options is completed by using UMODEL to perform the modal-split process. Once trips are assigned to their respective modes, the adequacy of the transportation system can be evaluated as well as the energy and air quality impacts.

MODEL APPLICATION

The area that comprises Genesee County, Michigan (1980 population, 324 703), was used as the case study. This area was selected because it represented a typical medium-sized urban area in its land use, socioeconomic, transportation system, and travel characteristics. The major metropolitan area in Genesee County is the City of Flint, which has a strong industrial base and a 1980 population of 166 739. The primary mode of travel is the automobile; less than 1 percent use public transportation.

Several work and nonwork models were developed and calibrated in this study. For the sake of brevity, only one work-trip model and one non-work-trip model will be discussed in detail in this paper. The distribution of trips among the five modes, developed from previous studies in the area, is shown in Table 1 for each trip purpose.

The models were calibrated by using a sample of the total trips. The selection of the sample size was designed to accomplish two objectives: (a) reduce the high computation costs associated with using a large number of trips, and (b) obtain a large enough number of trips to accurately calibrate the model, particularly for modes that experience very low ridership. The work-trip models were calibrated by using a 5 percent sample of the work trips (10 165 trip records), and the non-work-trip models were calibrated by using a 1.3 percent sample of nonwork trips (15 268 trip records).

Table 1. Observed trip distribution for work and nonwork trips.

Trip Purpose	Mode	Observed Trips	Percentage of Total
Work	Automobile, drive alone	175 690	86.4
	Automobile, one passenger	18 934	9.3
	Automobile, two passengers	4 395	2.2
	Automobile, three or more passengers	2 607	1.3
	Transit	1 721	0.8
	Total	203 347	
Nonwork	Automobile, drive alone	438 087	38.2
	Automobile, one passenger	367 304	32.1
	Automobile, two passengers	152 085	13.3
	Automobile, three or more passengers	183 002	16.0
	Transit	4 747	0.4
	Total	1 145 225	

Work-Trip Model

The formulation for this model is shown in Figure 2. Travel time and other variables (income pentile, population size, driving cost, etc.) were used to describe the disutility of using each mode. A small time penalty was used in the higher automobile-occupancy modes to reflect the time spent picking up each additional passenger. The modes, travel times, and other variables used in Figure 2 and throughout the rest of the paper are described below:

1. AUTOS PER POP--A density variable that indicates the number of automobiles owned divided by the population in the production zone of the trip;
2. BIAS--A constant developed by the ULOGIT program;
3. COST3--The out-of-pocket travel costs per vehicle occupant for the three-or-more-passenger automobile mode; this variable includes a distance cost (per vehicle mile) plus parking costs, where the costs are assumed divided equally among the vehicle occupants;
4. PENTILE--A five-level classification of income groups based on median zonal income for the production zone;
5. POP PER DU--The average household size in a zone associated with the production zone of the trip;
6. TIMEDA--The travel time for the automobile mode for the drive-alone trips, which includes in-vehicle time plus parking and "unparking" time;
7. TIME1--The travel time for the one-passenger automobile mode for work trips, which consists of

Figure 2. Formula specification for work model.

Mode	Coefficient	Variable
WDA	* A1	* TIMEDA
	+ B1	* PENTILE
	+ A BIAS	
WONE	* A1	* TIME1
WTWO	* A1	* TIME2
	+ B3	* POP PER ACRE
	+ P2 BIAS	
WTHREE	* A1	* TIME3
	+ C4	* COST3
	+ P3 BIAS	
TRANSIT	* A5	* WTRNS TIME
	+ B5	* AUTOS PER POP
	+ T BIAS	

the TIMEDA travel time plus a minute time penalty for picking up the passenger;

8. TIME2--The travel time for the two-passenger automobile mode for work trips, which consists of the TIMEDA travel time plus a minute time penalty for picking up the two passengers;

9. TIME3--The travel time for the three-or-more-passenger automobile mode for work trips, which consists of the TIMEDA travel time plus a minute time penalty for picking up the passengers;

10. TRANSIT--A dependent variable that describes mode of travel; transit mode (bus service) for work purposes;

11. WDA--A dependent variable that describes mode of travel; drive-alone automobile mode for work purposes;

12. WONE--A dependent variable that describes mode of travel; one-passenger (in addition to the driver) automobile mode for work purposes;

13. WTWO--A dependent variable that describes mode of travel; two-passenger automobile mode for work purposes;

14. WTHREE--A dependent variable that describes mode of travel; the trip is by the three-or-more-passenger automobile mode for work purposes; and

15. WTRNS TIME--The weighted time (minutes) by the transit mode, which consists of the in-vehicle time plus a constant times the walk time plus a constant times the wait time; it recognizes that 1 min of wait and walk time has a higher disutility than 1 min of in-vehicle travel time.

The values of the variables and the correlation matrix of the independent variables are shown in Figure 3. The independent variables were obtained from the calibration file developed in an earlier step. Figure 4 shows the final values of the coefficients that result from the ULOGIT calibration process.

Several statistical tests are also provided by

Figure 3. Statistical summary of independent variables used in work model.

THE VARIABLES USED FOR CALIBRATION ARE:

VARIABLE NO.	NAME	MEAN	STANDARD DEV.	LARGEST VALUE	SMALLEST VALUE	UNITS
1	TIMEDA	18.24	8.96	70.00	2.00	MINUTES
2	PENTILE	3.91	0.97	5.00	1.00	PENT
3	TIME1	19.32	8.99	71.10	3.10	MINUTES
4	TIME2	20.32	9.00	72.10	4.10	MINUTES
5	POP PER ACRE	15.06	19.79	268.69	0.00	POP/ACRE
6	TIME3	21.93	8.96	73.70	5.70	MINUTES
7	COST3	1.02	3.63	19.36	0.08	CENTS
8	WTRNS TIME	266.00	211.53	500.00	22.00	MINUTES
9	AUTOS PER POP	0.98	11.47	253.00	0.0	AUTO/POP

CORRELATION MATRIX OF INDEPENDENT VARIABLES:

	1	2	3	4	5	6	7	8
2	0.1640							
3	0.9970	0.1693						
4	0.9967	0.1696	0.9992					
5	0.0412	0.0709	0.0430	0.0432				
6	0.9971	0.1626	1.0003	0.9992	0.0421			
7	0.0579	0.0565	0.0585	0.0585	0.5053	0.0583		
8	0.3335	0.3287	0.3349	0.3348	-0.1324	0.3340	-0.0716	
9	-0.0126	-0.0883	-0.0123	-0.0123	-0.0366	-0.0125	-0.0112	-0.0185

Figure 4. Final coefficient values and other statistics for work model.

Mode	Variable or Bias Coefficient	Coefficient Value	T-Ratio	Pseudo R-Square
WDA	TIMEDA	0.2620	11.95	
	PENTILE	-0.1010	- 3.43	
	BIAS	-1.5290	-12.55	
WONE	TIME1	0.2620	11.95	
WTWO	TIME2	0.2620	11.95	
	POP PER ACRE	0.0110	2.27	
	BIAS	1.0760	11.08	0.680
WTHREE	TIME3	0.2620	11.95	
	COST3	-0.0740	- 5.02	
	BIAS	1.4480	12.47	
WTRAN	WTRNS TIME	0.0810	11.58	
	AUTOS PER POP	-0.0070	- 1.80	
	BIAS	0.8310	2.53	

Figure 5. Comparison of observed versus estimated trips for work model.

ALTERNATIVE	OBSERVED	ESTIMATED	STD. RESIDUAL	CORR. COEF.	CORR. RATIO	NO. CELLS
WDA	8784.0	8727.7	1.617	0.002	0.008	15
WONE	946.0	958.9	-0.439	0.000	0.001	7
WTWO	219.0	217.7	0.086	0.001	0.000	3
WTHREE	130.0	128.9	0.099	0.002	0.010	6
TRANSIT	86.0	118.4	-3.119	0.010	0.033	22

the ULOGIT program for the purpose of evaluating the calibrated model (Figures 4 and 5). These tests should be used carefully to avoid accepting a poor model as well as to avoid rejecting a good model.

Statistical Tests

The test used to assess the reasonableness of the model is to review the sign of the coefficients to determine whether the variables represent a utility or a disutility. If a variable, by intuitive judgment, is considered to be a disutility (or impedance to travel) and is actually represented as a utility, the validity of the model becomes questionable. The final values as provided by the ULOGIT report (shown in Figure 4) are given as disutilities. Therefore, if the final value of the coefficient is a positive value, the corresponding variable is a disutility and is interpreted as an impedance to travel. With this understanding, the variables used in the model formulations are as follows:

1. The travel-time variables (TIMEDA, TIME1, TIME2, TIME3, and WTRNS TIME) represent a disutility, which indicates that longer travel times will result in less tripmaking by the respective mode;
2. The PENTILE variable represents a utility for the WDA mode, which indicates that tripmakers in the higher-income category are more likely to use the automobile drive-alone mode;
3. The population-density variable (POP PER ACRE) represents a disutility factor for the WTWO mode, which indicates that areas with higher population density would generate a smaller number of two-passenger automobile trips;
4. The travel cost factor (COST3) represents a utility factor for the WTHREE mode, which indicates that increased out-of-pocket costs of driving would result in more three-or-more-passenger automobile trips; and
5. The AUTOS PER POP variable represents a utility for transit trips, which indicates that increased automobile availability would result in increased transit trips.

For all cases except AUTOS PER POP, the variables and coefficients adequately explain the expected travel characteristics. The automobile per population factor, however, results in some inaccuracy for the transit-trip estimates. Due to the problems with the AUTOS PER POP variable, it will be necessary to eliminate or replace this variable in further fine tuning of the model.

The t-ratio is used to measure the significance of the variable in the disutility equation (Figure 4). Considering a 95 percent confidence level (t-ratio = 1.96), all variables are considered significant in defining trip characteristics except for the automobiles per population variable used in explaining transit trips.

A comparison of the observed versus estimated trips is provided in Figure 5. This comparison displays an excellent match for trips by all modes except transit trips. The discrepancy that occurs in transit trips can be partly attributed to the small sample size (86 transit-trip records) used in calibrating the model. It should be noted that an effort to increase the number of transit-trip records in the sample may provide better results. But there would also be a proportional increase in trip records by all other modes in the sample, thus increasing the computer costs of the analysis. Other statistics that can be used to evaluate the model's acceptability include the pseudo R-square value (Figure 4) and the standardized residual (Figure 5).

Comparison of Work-Model Results with Observed Trip Tables

The report provided by ULOGIT that compares the observed and estimated trips (Figure 5) is a relatively weak statistical test and does not necessarily provide conclusive evidence regarding the model's adequacy. The ULOGIT reports are based on only a 5 percent sample of work trips. As a further test, the results of the work-trip models were compared with the total person trip table for work trips.

To accomplish this summary, the logit model with the utility or disutility coefficients (Figure 4) was used in allocating the total work-trip table among the five competing modes, following the modal-split procedure presented earlier. The results of modal split are given in the table below:

Mode	Observed Trips	Estimated Trips
Drive alone	175 690	174 870
One passenger	18 934	19 205
Two passengers	4 395	4 355
Three or more passengers	2 607	2 578
Transit	1 721	2 280
Total	203 347	203 288

In an attempt to test the goodness of fit of the models to the observed trip data on a trip interchange basis, the trip length frequency (TLF) curves for the observed trips were compared with the TLF curves for the estimated trips by each mode. This check would ensure that the trip data from the two sources were from the same population or distribution. This test, although not entirely conclusive, is a good indication of the acceptability of the models.

The comparison of TLF curves was obtained by using the UTPS program UFMTR. A visual comparison of the observed and estimated TLF curves showed a high degree of similarity in the curve shape and size, particularly for the drive-alone automobile mode.

A more accurate comparison between the observed

Table 2. Comparison of observed versus estimated TLF means and variances for work trips.

TLF	Drive Alone	One Passenger	Two Passengers	Three or More Passengers	Transit
Mean					
Observed	18.320[a]	17.930	17.924[a]	18.498[a]	40.152[a]
Estimated	18.279[a]	18.125	18.147[a]	18.320[a]	40.369[a]
Variance					
Observed	79.195[a]	93.990[a]	95.486[a]	91.193[a]	199.055
Estimated	81.271[a]	80.090[a]	82.500[a]	80.400[a]	263.571

[a]No significant difference at 95 percent level of confidence.

Table 3. Comparison of observed versus estimated TLF means and variances for nonwork trips.

TLF	Drive Alone	One Passenger	Two Passengers	Three or More Passengers	Transit
Mean					
Observed	12.317	13.236	12.580	12.364	47.261
Estimated	12.650	12.646	12.645	12.635	53.481
Variance					
Observed	52.784[a]	62.703[a]	57.418[a]	54.239[a]	250.003
Estimated	57.222[a]	56.889[a]	56.870[a]	55.831[a]	423.401

[a]No significant difference at 95 percent level of confidence.

and estimated TLF curves can be accomplished by comparing the means (t-test) and variance (F-test). The results of the t-tests, or test of means, is given in Table 2. This table shows that, except for one-passenger automobile trips, there were no significant differences in the mean trip lengths between the observed data and the estimated trips. The F-test is a comparison of variances of the TLF distribution. The F-tests also indicate an acceptable fit between the TLF curves from the model and the observed TLF curves in four out of five cases, with the exception of transit trips.

Non-Work-Trip Model

A five-mode non-work-trip model was used, similar to the work-trip model discussed above. The travel time variable was the primary variable used to describe the utility or disutility of using a particular mode for nonwork trips. Other variables used in the formulation include income, family size, and automobile availability. For the sake of brevity, only the final results of the nonwork model are presented in this paper.

Statistical Tests

For most of the variables used in the model, the sign of the coefficient adequately represents the expected utility or disutility. As in the case of the work-trip model, the AUTOS PER POP factor results in a slight inaccuracy in the transit-trip estimates. With a 95 percent confidence level, all variables were considered significant in defining the trip characteristics except for AUTOS PER POP. In the process of fine-tuning the model, the AUTOS PER POP variable should be replaced or eliminated.

A comparison of observed versus estimated trips indicated an acceptable match for all modes. Other statistics, such as the pseudo R-square value and the standardized residual, also indicated an acceptable model.

Comparison of Non-Work Model Results with Observed Trip Tables

To further evaluate the predictive capability of the model, a comparison was made of the estimated results with the total observed nonwork trip tables, as given in the table below:

Mode	Observed Trips	Estimated Trips, Model Results
Drive alone	438 087	427 874
One passenger	367 304	366 755
Two passengers	152 085	151 878
Three or more passengers	183 002	193 534
Transit	4 767	9 597
Total	1 145 245	1 149 638

As this table shows, the estimated trips by the model are reasonably close to the observed data for all modes except transit.

A visual comparison of the TLF curves for the observed versus estimated trips shows a similarity in the curve form for all automobile-occupancy levels. A statistical comparison for the TLF means indicates that there is a statistical difference in the mean travel time for all modes (at a 95 percent level of confidence), although the numerical difference does not appear significant (see Table 3). The test for variance indicates no significant difference between the observed and estimated results for automobile modes (Table 3).

SENSITIVITY ANALYSIS

One of the most important attributes in a travel-demand model is its sensitivity to changes in transportation system characteristics. A model should be developed so that it can accurately reflect the possible impacts that result from changes in the transportation system associated with the new alternative. The model must be able to test new transportation strategies (or variations thereof) that are of concern to transportation planners. In medium-sized urban areas, these transportation system strategies may include ridership incentive programs, park-and-ride facilities, new transit systems, and other TSM concepts.

The ULOGIT program produces a table of elasticities that can be used to evaluate the sensitivity of the model to changes in each variable. The elasticities are defined as the percentage in alternative choice probability (i.e., demand) expected from a 1 percent change in the associated independent variable (5). The elasticities provided by ULOGIT are only defined at the mean value of the independent variables used in the model formula specification. The elasticities are likely to be different at different values of independent variables.

To illustrate the sensitivity of these models, the modal-split results of three transportation system alternatives are presented by using the work model. The three alternatives were developed for the study area as a part of ongoing planning activities in the area (4,7).

The principal attributes of these alternatives are as follows:

1. Alternative A: Decrease total transit travel time by increasing the frequency of bus service. The average wait time was reduced by 50 percent to represent an increase in service.
2. Alternative B: Addition of three transit routes to the base transit system and an increase of operating headways to 30 min (from the existing 20-min headways).

Table 4. Modal-split results for changes in transit operating strategies by using adjusted work model.

Mode	Observed Trips	Alternative A	Alternative B	Alternative C
Drive alone	175 690	173 306	176 302	172 165
One passenger	18 934	19 026	19 376	18 908
Two passengers	4 395	4 316	4 397	4 295
Three or more passengers	2 607	2 553	2 607	2 535
Transit	1 721	5 786	1 179	9 387
Total	203 347	204 987	203 861	207 290

3. Alternative C: Addition of three transit routes as in alternative B with a reduction of headways to 10 min.

The results of this analysis are presented in Table 4. The reduction of waiting time by 50 percent (alternative A) resulted in increasing transit ridership by a factor of 3 over the base condition. Transit use increased from 0.9 percent of the total work trips to 2.8 percent of the total work trips. Travel by the automobile-occupancy modes each decreased by a small amount.

Alternative B (adding three transit routes while increasing bus headways to 30 min) resulted in a sizable reduction in transit ridership. As a result of the reduction in transit ridership, a slight increase in each automobile-occupancy mode was recorded.

Alternative C (adding three routes and decreasing bus headways to 10 min) resulted in a significant increase in the use of transit over the base conditions. This increase is approximately 5 times the base condition ridership of 1721 daily transit work trips. As a result, ridership for each automobile-occupancy mode decreased by approximately 2 percent.

These results indicate that the model is highly sensitive to changes in travel time. Changes in transit ridership also have some form of impact on travel demand for all four remaining modes. Changes in the travel system for the automobile modes can be tested in a similar manner to determine the sensitivity of the model to changes in these variables.

CONCLUSIONS

The purpose of this study was to investigate the feasibility of using the logit approach for modal- and multimodal-split purposes in medium-sized urban areas with the use of commonly available data. A number of conclusions can be drawn from this study regarding the logit approach, the feasibility of using aggregate data for demand-estimation purposes, and the transferability of the model to other urbanized areas of similar sizes. The conclusions are outlined below:

1. The logit model is a valid approach to travel-demand modeling for multimodal analysis. The use of a utility or disutility function to describe mode selection based on impedance to travel is consistent with the behavioral aspects of the tripmaker decision process and the effect of variables on the travel decision.
2. The logit approach lends itself to the simultaneous modeling of several modes that represent various levels of automobile occupancy and transit. The ULOGIT program can calibrate up to 10 modes at a time. It is extremely difficult, if not virtually impossible, to accomplish this task by using the traditional branching or submodal-split approach.
3. The study shows that the lack of disaggregate household data is not a significant problem for logit models. Although it is desirable that such disaggregate data be used when available, in the absence of such data the use of aggregate data can produce valid and acceptable results.
4. Many of the statistical tests and model-evaluation measures produced by the ULOGIT computer program are inconclusive. The statistical tests should be used primarily for the purpose of eliminating unacceptable model formulations. The selection of the best model requires a clear understanding of all the statistical tests and should not be based on the highest statistics alone. In addition, model results should be compared with the total person trip table to properly evaluate the models' capability to estimate demand.
5. When developing the utility or disutility formulations, the explanatory variables should be carefully selected to reflect the actual modal-choice decision criterion used by the tripmaker. In addition, the explanatory variables must be quantifiable, predictable, and available for use in the design year. The use of variables that do not have the above properties should be discouraged. Furthermore, the model should be designed such that it is sensitive to the transportation alternatives that are to be tested.

This paper indicates that the potential for applying this approach in other urban areas is quite high, although further calibration and validation is warranted before a more widespread application of this concept is practiced. Specifically, the following recommendations are made:

1. Studies should be directed toward identifying various time or cost penalties related to high-occupancy vehicles (i.e., time or cost penalties associated with picking up and dropping off passengers).
2. Further studies should be directed toward selecting proper sample sizes for calibrating the model. In particular, there is a need to develop measures for designing sampling rates that would take into account the trade-offs between the predictive quality of the model and the associated computer costs for larger sample sizes.
3. The logit concept should be used in other medium-sized urban areas to further test the logit modeling process. Because the type of data used in the Flint case study is commonly available for similar medium-sized urban areas, the transferability of the model to other urban areas does not appear to pose any major problem.
4. When employing the logit modeling process to a new area, the specific logit models developed for other cities must be recalibrated. In recalibrating an existing model to a new area, it is advisable to use previously calculated values as initial estimates of the coefficients. This may reduce the calibration effort as well as the computer costs.

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