Trip Distribution Using Composite Impedance

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In this paper the theory and results of a trip-distribution model that uses a multimodal composite definition of impedance as its measure of separation, instead of highway time, are presented. The distribution model is part of a complete travel-demand model chain developed for the New Orleans region. This model chain is briefly described, and its special features of income stratification and connectivity among programs are emphasized. The disutility functions of a three-mode logit modal-choice model are used to develop modal impedance values. The structure and coefficients of these equations are discussed. Two alternative methods for combining these modal impedances are presented: harmonic mean and log sum. A special technique for calibrating the F factor curves was developed to circumvent shortcomings in the urban transportation planning system (UTPS) software. The results of the calibration are presented. These results indicated that the log sum formula produced better results than the harmonic mean formula, based on various observed and estimated comparisons. In addition, the log sum composite impedance-based model proved suitable only for home-based work trips. Unsatisfactory results for the other trip purposes led to the use of off-peak highway time for those purposes. Results for home-based other and non-home-based models are also presented. The conclusions of this analysis are that a distribution model can be successfully calibrated by using composite impedance; that, at least in this case, the log sum formula worked better than harmonic mean; and that a successful alternative to the standard AGM gravity model calibration process can be developed.

The theory and results of a trip-distribution model that uses a composite definition of impedance as its measure of separation, instead of highway time, are presented in this paper. The premise that such a model is inherently logically superior to a gravity model based on highway time is accepted as a given. This superiority involves a composite impedance-based model that is sensitive to the characteristics of all modes and provides for improved connectivity between the distribution and modal-choice models. This should, in theory, produce more reasonable estimates of trip distribution. The distribution model is part of a complete travel-demand model chain developed for the New Orleans region. Previous work is reviewed here; the accompanying logit modal-choice models are described; and alternative methods of combining impedances, a different technique for calibrating gravity models, and the final results are presented.

PRIOR RESEARCH

The use of composite impedance in distribution models is not new. For example, an early reference to a generalized resistance formulation for the gravity model is a 1973 paper by Manheim (1) based on his earlier work (2). Wilson (3) also describes a composite generalized cost function. Much of the recent work in this field has focused on the joint choice type of model. By combining destination choice and modal choice (and often trip frequency) into a single model (generally by using a logit structure), this type of model effectively incorporates the impedances of all modes and the socioeconomic status of the traveler into the trip-distribution process. There are numerous references to and examples of this model type in the literature (4,5), with perhaps the best known of these being the Metropolitan Transportation Commission (MTC) model set (6).

However, the New Orleans model chain uses the traditional sequential application of models, and there appears to be but one previous attempt at using composite impedance in this context. In 1975 a similar set of models was developed for the Regional Transportation District in Denver (7). That study used modal-choice logit coefficients to define impedance. Alternative methods of combining impedances were reviewed, and a parallel resistance (harmonic mean) formulation was selected.

Basically, the New Orleans distribution models are a direct extension of the Denver work. The major changes are that separate models are developed for each income level and the log sum method of combining impedances was used. The log sum method, which is simply the natural logarithm of the denominator of the modal-choice logit equation, was also used in the San Francisco MTC models (6).

MODEL CHAIN

The distribution model can best be described by placing it in the setting of the entire travel model chain (see paper by Schultz elsewhere in this Record). The New Orleans model chain consists of the traditional generation, distribution, and modal-choice models. What distinguishes these models is that they are entirely income stratified and highly connected with each other. The generation models use an elaborate cross-classification structure, including the capability of estimating trip productions and attractions for each of four income levels (quartiles). The modal-choice models consist of a three-mode logit structure, which contains bias variables based on income level.

One of the criticisms of the traditional type of travel-demand models is that the models are applied sequentially, independent of each other. It is generally recognized that actual travel decisions are seldom made in this fashion. Rather, decisions on frequency, destination, mode, and route tend to be interrelated. The use of composite impedance is an attempt to address this concern. The modal-choice and distribution models are tied together because the coefficients of the logit models are used to define the composite impedance value. Therefore, the distribution of trips is sensitive to both highway and transit service levels, travel cost as well as time, and the income level of the traveler. The high level of transit service in New Orleans makes this multimodal definition of impedance especially meaningful. This multimodal sensitivity is also essential to one of the goals of this model chain: to be able to respond more accurately to the existence of transit guideways, high-occupancy vehicle (HOV) facilities, and a wide range of transportation policy variables.

The results of the model calibration indicated that the composite impedance formulation was suitable only for the work trip purpose. For the home-based other and non-home-based trip models, composite impedance could not successfully be used, and thus highway time was used. For the work model, the log sum method of combining impedance gave better results than the harmonic mean formulation. Finally, all three models were calibrated to a high degree of accuracy, with K factors used sparingly and only for trips crossing major geographic barriers.

MODAL-CHOICE DISUTILITY FUNCTIONS

As previously mentioned, a three-mode logit modal-choice model was calibrated for each trip purpose (8). These models are defined in terms of their disutility equations for each mode, as given in

Tables 1 and 2. As the equations in Table 1 indicate, travel disutility is a linear function of the time and cost of the transit, drive alone, and group automobile modes, and other service characteristics such as number of transfers and transit accessibility. Also, the income level of the traveler is a prime influence on perceived disutility. The differential effect of walk access to transit versus automobile access to transit on modal choice is defined through the use of an automobile access penalty dummy coefficient in the transit disutility equation. The variables are described in more detail in Table 3. For the work trip purpose, peak-hour impedance values were used; for home-based other and non-home-based purposes, off-peak values were used.

The mode and variable definitions for these equations are similar to other modal-choice models recently developed for Minneapolis-St. Paul (9), Seattle (10), Houston (11), St. Louis (12), and Buenos Aires (13). The group mode consists of persons in automobiles with two or more occupants. A separate logit submodel is used to estimate the proportion of two-person, three-person, and four or more person trips in order to determine the average group occupancy for each interchange. The transit and highway variables are created from standard Urban Transportation Planning System (UTPS) network analysis programs (14) and special submodels are used to estimate accessibility, terminal time, and parking cost. The calibration data consisted of a comprehensive, home interview origin-destination survey conducted in the New Orleans region in 1960.

The coefficients and the final list of variables were developed by using ULOGIT on a sample of the survey file, followed by disaggregate validation and adjustment by using the full survey file. The coefficients are comparable to coefficients from other cities, exhibit internal consistency, and have acceptable t-ratios (see Tables 1 and 2). The following observations support the reasonableness of these equations:

1. The out-of-vehicle time coefficients exceed those for in-vehicle time;
2. The model is much more sensitive to automobile access time to transit than to time spent on the transit vehicle;
3. The ratio of the time coefficient to the cost coefficient, which is the implied value of travel time, is approximately one-third to one-half the average 1960 regional income in cents per minute; and
4. The income bias coefficients indicate that as income level increases, there is a lower propensity to use transit, and within the automobile mode, a higher propensity to be a driver rather than a passenger.

COMPOSITE IMPEDANCE CALCULATION

The previous section describes how impedance is defined for each mode. The remaining challenge is to combine the three impedances into one value. For this task, the following conditions must be met.

1. The combined value must decrease as any of the modes becomes better, i.e., declines in time or cost.
2. The combined value must increase if a mode is not available [i.e., an interchange with even unsatisfactory transit service must have a better (lower) impedance than one with no service at all].
3. The value must lie between 1 and 127, inclusive. The UTPS program AGM assumed that the input impedance values are stored as 1-byte matrix elements. The highest value that can be represented in this format is 127.
4. The distribution of values within this range should be reasonable; i.e., they should not be concentrated at the top or bottom of the range.

It was ascertained that at least two mathematical formulations meet these criteria. One formulation is a variation of the harmonic mean function:

Table 1. Modal-choice disutility equations.

Mode	Equation
Home-based work trips	
Transit disutility	0.0332 * WALK + 0.0769 * WAIT1 + 0.0319 * WAIT2 + 0.0078 * FARE + 0.0145 * TRN RUN + 0.1005 * AUTO ACC (4.07) (20.21) (8.85) (10.45) (6.72) (2.59) + 0.0588 * TXFER + Auto Access Penalty (I) * AUTO CONN (3.59)
Drive-alone disutility	0.0693 * HWY EXC + 0.0145 * HWY RUN1 + 0.0078 * HWY CST1 + 0.02145 * PRK CST1 + Income Coefficient (1, I) (4.94) (6.72) (10.45) (10.45)
Group automobile disutility	0.0174 * HWY EXC + 0.0145 * HWY RUNG + 0.0078 * HWY CSTG + 0.02145 * PRK CSTG + Income Coefficient (G, I) (1.74) (6.72) (10.45) (10.45)
Home-based other trips	
Transit disutility	0.0165 * (WALK + WAIT1 + WAIT2) + 0.0116 * FARE + 0.0066 * (TRN RUN + AUTO ACC) – 0.0183 * TRN DACC25 (7.45) (9.55) (-22.91) + Auto Access Penalty (I) * AUTO CONN
Drive-alone disutility	0.3403 * HWY EXC + 0.0066 * HWY RUN1 + 0.0116 * HWY CST1 + 0.0319 * PRK CST1 + Income Coefficient (1, I) (25.98) (7.45) (9.55) (9.55)
Group automobile disutility	0.2828 * HWY EXC + 0.0066 * HWY RUNG + 0.0116 * HWY CSTG + 0.0319 * PRK CSTG + Income Coefficient (G, I) (28.50) (7.45) (9.55) (9.55)
Non-home-based trips	
Transit disutility	0.0328 * (WALK + WAIT1 + WAIT2) + 0.0047 * FARE + 0.0131 * (TRN RUN + AUTO ACC) + 0.0750 * TXFER (9.41) (2.75) (9.41) + 2.7472 * AUTO CONN (4.91)
Drive-alone disutility	0.2423 * HWY EXC + 0.0131 * HWY RUN1 + 0.0047 * HWY CST1 + 0.0291 * PRK CST1 + Income Coefficient (1, I) (20.14) (9.41) (2.75) (2.75)
Group automobile disutility	0.3048 * HWY EXC + 0.0131 * HWY RUNG + 0.0047 * HWY CSTG + 0.0291 * PRK CSTG + Income Coefficient (G, I) (25.58) (9.41) (2.75) (2.75)

Note: Disutilities must be multiplied by –1 before taking the exponential in the logit equation. Numbers in parentheses represent t-ratios. T-ratios were not calculated for the work and other automobile access penalty coefficients, or the non-home-based coefficient on TXFER. See Table 2 for explanation of bias coefficients used for the equations.

Table 2. Bias coefficients for modal-choice disutility equations.

Income Group[a] (I)	Automobile Access Penalty Coefficient	Income Coefficients: Drive Alone (1, I) Coefficient	Drive Alone (1, I) t-Ratio	Group Automobile (G, I) Coefficient	Group Automobile (G, I) t-Ratio
Home-based work trips					
1	1.4165	1.4014	13.74	1.6733	21.14
2	1.0683	0.7979	8.24	1.2677	18.89
3	0.4943	−0.0750	−0.32	0.8939	10.01
4	−0.2245	−0.6783	−6.59	0.6140	7.83
Home-based other trips					
1	2.9661	0.0934	9.06	−1.5281	−24.40
2	2.3095	−1.1802	−21.00	−2.2168	−35.62
3	1.9305	−2.1397	−30.61	−2.7419	−44.41
4	1.4125	−2.9294	−38.33	−3.1109	−50.70
Non-home-based trips					
1		−1.3447	−11.73	−1.3496	−11.52
2		−1.9311	−17.53	−2.1027	−17.19
3		−2.6904	−24.48	−2.5040	−21.67
4		−3.0689	−27.57	−2.7298	−23.35

Note: See Table 1 for equations used for bias coefficients.
[a]Income groups are divided as follows: 1 = low, 2 = low-middle, 3 = high-middle, and 4 = high.

Table 3. Variables used in modal-choice calibration.

Acronym	Description of Variable	Units of Measure
Transit variables		
TRN RUN	In-vehicle time from the transit network, not including automobile access time	Minutes
AUTO ACC	Automobile access time from the transit network	Minutes
WALK	Walk access time from the transit network	Minutes
WAIT1	Transit boarding time for the first transit vehicle from the transit network	Minutes
WAIT2	Time spent transferring from the transit network	Minutes
TXFER	Number of transfers from the transit network	Number
FARE	Transit fare	Cents
AUTO CONN	Dummy variable signifying if an automobile was required to access the transit system (0 is no, 1 is yes)	–
TRN DACC 25	Percentage of regional employment within 25 min of total transit time from destination zone	Percent
Highway variables		
HWY RUN1	Highway in-vehicle time from highway network for one person per car (drive alone) trips	Minutes
HWY RUNG	Highway in-vehicle time for group automobile trips (same as HWY RUN1 plus an additional time for each passenger)	Minutes
HWY CST1	Highway operating cost for one person per car trips	Cents
HWY CSTG	Highway operating cost for group trips	Cents
PRK CST1	Avg parking cost for one person per car trips	Cents
PRK CSTG	Avg parking cost for group trips	Cents
HWY EXC	Time spent parking and unparking an automobile; the sum of highway terminal time at the origin zone and the destination zone (also called highway excess or terminal time)	Minutes

$$C.I. = K / \sum_{i=1}^{3} [A(i) + C] \qquad (1)$$

where

C.I. = value of composite impedance,
A(i) = modal choice disutility function for mode i (i = 1,2,3),
C = constant chosen such that all A(i)'s are positive, and
K = constant chosen such that all C.I.'s are between 1 and 127, inclusive.

This formula is simply the reciprocal of the sum of the modal impedances, scaled to represent suitable values. The second formulation sums the exponential of the disutility function for all modes, takes the reciprocal of the sum, and takes the natural logarithm of this reciprocal. This is called the log sum method, and is described as follows:

$$C.I. = K * \ln \left\{ C / \sum_{i=1}^{3} \exp[-A(i)] \right\} \qquad (2)$$

Both of these functions meet the criteria previously described, but little was known about the ability of either to perform as a measure of spatial separation. Therefore, both measures were tested by calibrating the home-based work trip-distribution model twice, each time by using a different measure. The choice would then be made on the basis of whichever formulation provided the closer match to observed conditions, based on average trip length and other such measures.

CALIBRATION TECHNIQUE

The New Orleans distribution model uses the standard gravity model form (15). This model postulates that the number of trips for a given zone interchange is proportional to the number of trip productions at the origin zone and the number of trip attractions at the destination zone, and inversely proportional to the travel impedance between the two zones. The relationship with impedance is generally described by a nonlinear function that relates impedance to a nondimensional F factor (also called friction factor).

The usual calibration process involves determining the relationship between the impedance values and the F factors such that the distribution of estimated trips by impedance matches that of the observed trips. Additional adjustment factors (K factors) are used to help match observed and estimated trips by geographic stratification (such as districts). For this project, separate models were developed for each trip purpose and for each of four income levels. Observed person trips came from the home interview survey.

Initially, it was assumed that the UTPS program AGM, operating in the so-called SAC mode, would be able to automatically calculate the proper F factors. However, this function of program AGM was not operating correctly at that time and an ad-hoc method of calibrating the F factors was developed. This method used essentially the same technique as described in the AGM program documentation. F factors are calculated by using a gamma function, i.e.,

$$F(I) = A * I^{B} * EXP(G * I) \qquad (3)$$

where

F(I) = F factor for impedance value I,
A,B, and G = calibrated coefficients, and
EXP = exponential function.

This function was judged to be adequate because there is considerable documentation that it simulates the relationship between F factors and impedance adequately. Calibration of a distribution model consists mainly of fitting this curve. This was done as follows.

1. Apply program AGM in the apply-and-calibrate (AC) mode, which reports the observed and estimated trips stratified by each unit of impedance.
2. The observed and estimated trips and the F

factors used in that run were then keypunched into a file that could be used by Statistical Package for the Social Sciences (SPSS) programs (16).

3. The SPSS subprogram REGRESSION was then used to obtain a least squares fit for the coefficients A, B, and G (after suitable transformation of the variables).

4. New F factors were calculated by using the new coefficients, and program AGM was reapplied. The observed and estimated trip lengths were then compared, and if the results were inadequate, steps 2-4 were performed again.

The results were judged by a visual inspection of the impedance distribution and by comparing the average values for composite impedance and trip length. By using this technique, a satisfactory set of F factors could be obtained in between six and nine iterations.

RESULTS

The results of the impedance calculations are given in Table 4. The composite impedance values differ markedly by income level and are biased in the proper direction. That is, the lower-income levels are associated with higher impedance. This reflects the fact that lower-income persons tend to have lower mobility (for example, they are less likely to own automobiles). The composite values also indicate a larger spread than the time values, which may suggest more specific relationships between composite impedance and F factors. These statistics indicate that the composite impedance formulation behaves mathematically. This increases the confidence with which it can be used in gravity model development.

Table 4. Summary of observed impedance values.

Purpose and Income Level[a]	Average Value[b]	Lowest Value[c]	Highest Value[c]	Standard Deviation
Home-based work trips				
1	62.189	44	111	9.908
2	56.338	38	98	8.695
3	47.171	29	84	8.596
4	38.063	21	77	8.670
Home-based other trips				
1	7.579	1	43	4.942
2	7.965	1	39	5.334
3	8.214	1	44	6.118
4	7.692	1	44	5.679
Non-home-based trips				
1	7.720	1	36	5.263
2	7.671	1	43	5.451
2	7.710	1	39	5.392
4	7.520	1	39	5.130

[a]Income level is divided as follows: 1 = low, 2 = low-middle, 3 = high-middle, and 4 = high.

[b]The values for home-based work represent log sum composite impedance. All other values represent highway time. All highway times used were off-peak highway times without terminal time.

[c]Highest and lowest values that contain observed trips.

The results of calibrating the home-based work model with both sets of composite impedance functions are given in Tables 5-7. These comparisons indicate that the log sum results are superior to those obtained with the harmonic mean formula. The basic philosophy of these comparisons was that, if the model could be calibrated by using one type of impedance and could be shown to properly replicate the means of a different (but related) type of impedance, the calibration would be considered successful. The log sum formulation estimates average

Table 5. Comparison of two composite impedance formulas: highway running time (min).

Income Group[a]	Harmonic Mean Observed	Harmonic Mean Estimated	Harmonic Mean Percent Error	Log Sum Observed	Log Sum Estimated	Log Sum Percent Error
1	10.17	10.67	4.92	10.17	10.82	6.39
2	10.18	11.02	8.25	10.18	10.59	4.03
3	10.87	11.59	6.62	10.87	10.97	0.92
4	11.16	11.87	6.36	11.16	11.26	0.90
All income groups	10.68	11.39	6.65	10.68	10.94	2.43

Note: These values represent the home-based work purpose gravity model runs, without K factors.

[a]Income groups are divided as follows: 1 = low, 2 = low-middle, 3 = high-middle, and 4 = high.

Table 6. Comparison of two composite impedance formulas: highway distance (mile).

Income Group[a]	Harmonic Mean Observed	Harmonic Mean Estimated	Harmonic Mean Percent Error	Log Sum Observed	Log Sum Estimated	Log Sum Percent Error
1	4.29	4.53	5.59	4.29	4.64	8.16
2	4.29	4.70	9.56	4.29	4.52	5.36
3	4.72	5.15	9.11	4.72	4.80	1.69
4	4.91	5.29	7.74	4.91	4.96	1.02
All income groups	4.61	4.99	8.24	4.61	4.75	3.04

Note: These values represent the home-based work purpose gravity model runs, without K factors.

[a]Income groups are divided as follows: 1 = low, 2 = low-middle, 3 = high-middle, and 4 = high.

Table 7. Comparison of two composite impedance formulas: number of intrazonal trips.

Income Group[a]	Harmonic Mean Observed	Harmonic Mean Estimated	Harmonic Mean Percent Error	Log Sum Observed	Log Sum Estimated	Log Sum Percent Error
1	936	882	−5.77	936	857	−8.44
2	2,202	1,854	−15.80	2,202	2,396	8.81
3	2,895	2,471	−14.65	2,895	3,437	18.72
4	3,113	2,374	−23.74	3,113	2,866	−7.93
All income groups	9,146	7,581	−17.11	9,146	9,556	4.48

Note: These values represent the home-based work purpose gravity model runs, without K factors.

[a]Income groups are divided as follows: 1 = low, 2 = low-middle, 3 = high-middle, and 4 = high.

highway travel time and distance considerably better than did the harmonic mean formulation, except for the lowest income quartile. When intrazonal trips are compared, the log sum approach is superior for total trip estimation, but slightly inferior for the low and high-middle income quartiles. In comparing major trip patterns, such as trips across the Mississippi River, the harmonic mean model overestimated the observed data by 69 percent, whereas the log sum model overestimated by only 44 percent (before K factors were applied, in both cases). In addition, a comparison was made of the number of district interchanges (there are 20 districts) for which the difference between observed and estimated trips was greater than 100 trips and the percentage difference was greater than 15 percent. The harmonic mean model had 68 such district interchanges, whereas the log sum model had 56.

Based on this analysis, the log sum formulation was chosen to complete the calibration of the distribution model. Because the log sum formula worked well for home-based work trips, this method was used for home-based other and non-home-based trips as well. An F factor equation for home-based other trips was calibrated, and the model was applied for a validation check. However, in this case, in comparing observed and estimated trips with respect to highway time and distance, the estimated trips showed a much higher trip length. The estimated trips were considerably less than the observed trips in the 1-, 2-, and 3-min time range and considerably higher in the 4-, 5-, and 6-min time range. At times greater than approximately 7 min, the two distributions were similar. Considerable thought was given to correct this imbalance in distribution, but no methodology appeared to offer any reasonable chance of successful calibration. Because of these results, the home-based other distribution model was calibrated by using off-peak highway travel time rather than composite impedance.

Similar results were obtained for the non-home-based model calibration, leading to the same solution: use of off-peak highway time instead of composite impedance. Off-peak highway time was also used for the remaining models (taxi, internal-external, and truck).

There is speculation that the lack of success in using composite impedance in the nonwork models is related to the nature of nonwork trips compared with work trips. Work trips are methodical and repetitive, and the commuter may actually have more knowledge than the nonwork traveler about his modal options and their associated impedances. Nonwork trips are less structured, and perhaps less thought is given to alternative modes for such trips. That is, cost considerations and the availability of transit service may not strongly affect nonwork destination choice.

The calibrated F factor equations for all trip purposes are given in Table 8, with the F factors being defined by the three coefficients of the gamma distribution. All coefficients are statistically significant, and the correlation coefficient (R^2), which compares the required F with the calculated F, was greater than 0.90. The regression program equations have been adjusted, where necessary, to ensure that the highest F value is not more than 999,999, in order for the data to be acceptable to AGM.

Table 8. F factor equations.

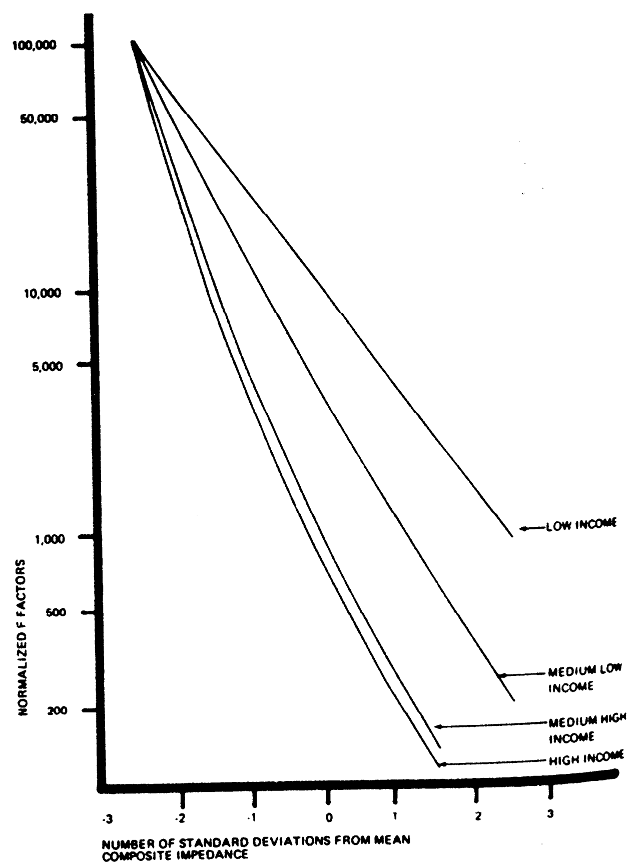
Purpose and Income Group[a]	Equation Coefficient Values[b] A	B	G
Home-based work trips			
1	4,296,752	0	−0.09300397
2	EXP (26.82271)	−3.153498	−0.0836755
3	EXP (34.10976)	−6.800698	−0.024841
4	EXP (28.39026)	−4.819197	−0.041024
Home-based other trips			
1	1,064,302	−1.055559	−0.1054066
2	1,070,772	−1.292004	−0.09307232
3	647,077	−1.838836	−0.03701391
4	1,033,560	−1.838298	−0.05231526
Non-home-based trips			
1	663,504	−0.6655663	−0.1231575
2	869,114	−0.9009789	−0.1125171
3	267,378	−0.9540237	−0.1127642
4	371,881	−0.7850539	−0.138105

[a] Income groups are divided as follows: 1 = low, 2 = low-middle, 3 = high-middle, and 4 = high.
[b] F factors are calculated by using the equation: $F(I) = A \cdot I^{B} \cdot EXP(G \cdot I)$; where I is the composite impedance for work trips and highway time for the other trip purposes.

The primary reason for calibrating the distribution models by income quartile was the hypothesis that tripmakers in different income levels would react differently to the impedance measure. Although the gamma function coefficients are different for the four income levels, it is hard to ascertain the true difference because the F factors are relative, and the mean composite impedance values are different by income level. To test the hypothesis that the F factors are truly different by income level, a set of normalized F factors were calculated by using the mean composite impedance values and the standard deviations from the mean. Normalized F factors were developed by adjusting the constant term (the A coefficient in the gamma equation) so that the F factor would (arbitrarily) equal 100,000 at a composite impedance value, which was 2.5 standard deviations less than the mean value. This comparison is shown in Figure 1. In essence, the comparison shows that F factors for the lower incomes are less sensitive to the impedance values. It would not appear reasonable, though, to use this comparison to draw the conclusion that poorer people like to travel more than richer people. Perhaps a better explanation is that the lower-income traveler has fewer destinations to choose from, thereby reducing the impact of travel impedance on travel behavior, at least on distribution.

Most calibration reports on distribution models give the observed and estimated trips stratified by highway travel time. For distribution models calibrated by using highway time, these comparisons nor-

Figure 1. Home-based work normalized factors plotted against standard deviation units of composite impedance.



ually indicate a great deal of agreement between the observed and estimated trips, which is only reasonable because the F factors are directly related to highway time. Because the spatial measure used in this model was composite impedance, of which highway travel time was only one component, a comparison of the observed and estimated trips measured against highway travel time would be a useful validation test, as mentioned previously. These comparisons are shown graphically in Figures 2-6. As can be seen from the data in these figures, the estimated trips agree with the observed trips extremely well. The comparisons by income level are similar to normal gravity model trip-distribution comparisons. When the trips for all incomes are combined (Figure 6), the observed trip pattern is much smoother and the estimated trips compare extremely well with the observed trips.

After calibrating the F factors, the next step in the calibration procedure was to ascertain the trip movements that were inadequately simulated and that had specific attributes that would be identifiable

Figure 2. Comparison of trip distributions for low income home-based work trips.

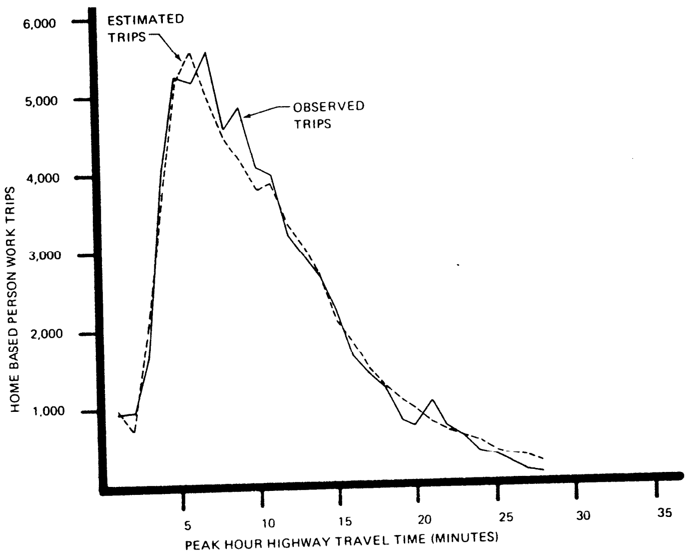


Figure 3. Comparison of trip distributions for low-medium income home-based work trips.

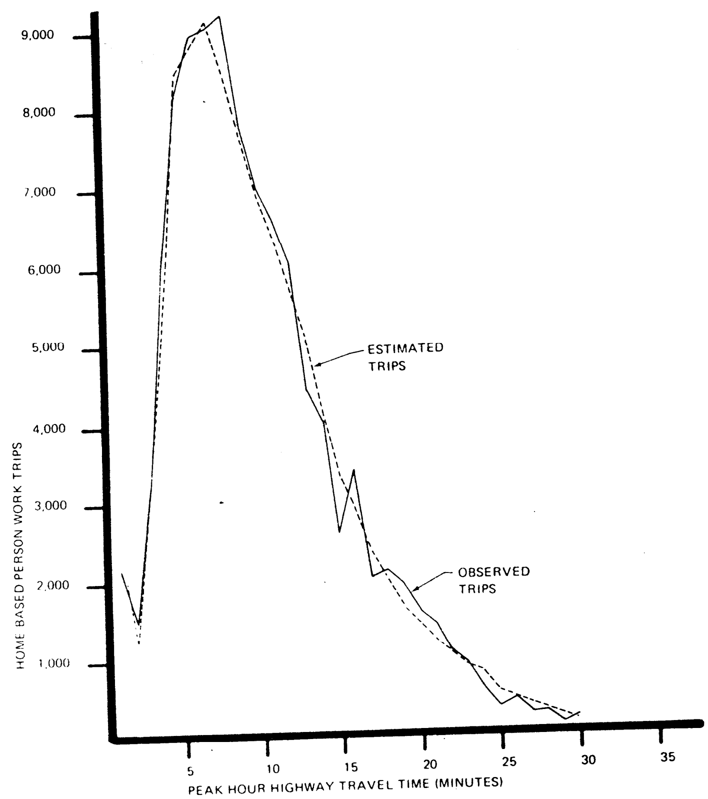


Figure 4. Comparison of trip distributions for high-medium income home-based work trips.

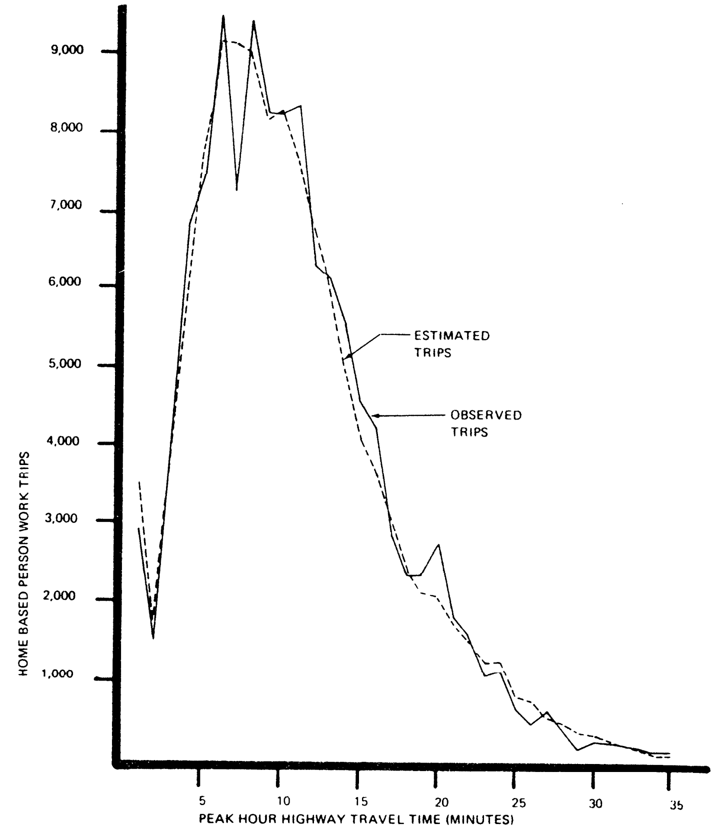


Figure 5. Comparison of trip distributions for high income home-based work trips.

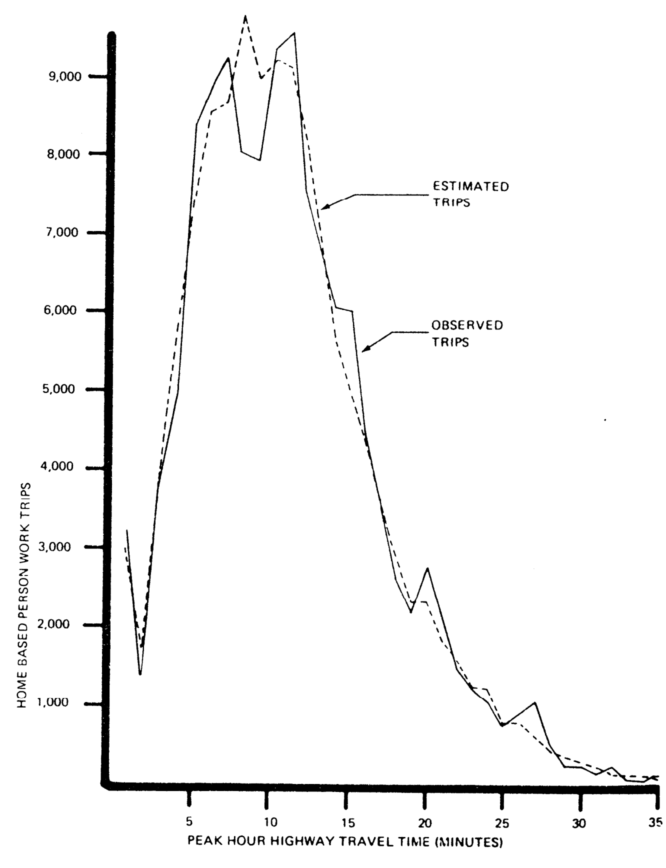
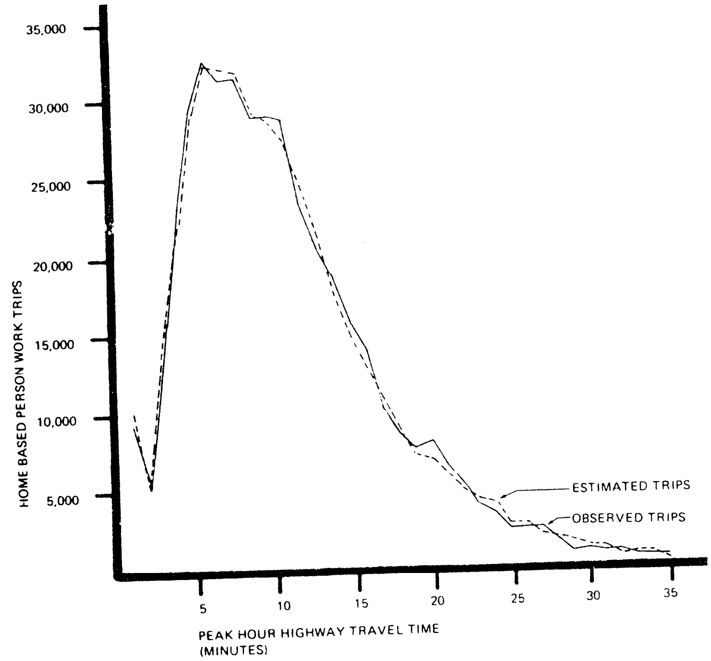


Figure 6. Comparison of trip distributions for all home-based work trips.



in the future. The two most important movements meeting these criteria were the water crossings, specifically the trip movements across the Mississippi River and the Navigational Canal. As can be seen from the data in Tables 5-7, even the log sum approach overestimated these trip movements for work trips. River crossings are traditionally difficult to estimate because there is a psychological factor associated with crossing this type of barrier. The calibration method to estimate the K values was to summarize the observed and estimated trips crossing the barrier and calculate the K value as a ratio of these two values. Because the K value appears both in the numerator and the denominator of the distribution formula, this formulation does not estimate a correct K factor in one iteration. Several iterations were required to develop K factors that produced adequate results. The final K factors are given in Table 9.

Table 9. Final K factors.

Purpose and Income Group[a]	K Factors: Across Mississippi River	K Factors: Across Navigational Canal
Home-based work		
1	0.496	0.798
2	0.463	0.962
3	0.703	0.896
4	0.660	0.895
Home-based other		
1	0.197	0.972
2	0.184	0.897
3	0.241	0.899
4	0.241	1.000
Non-home-based		
1	0.365	0.702
2	0.316	0.860
3	0.368	0.818
4	0.351	0.805

Note: For trips that cross both waterways, the Mississippi K's are used.

[a]Income groups are divided as follows: 1 = low, 2 = low-middle, 3 = high-middle, and 4 = high.

Once the F factors and K values were calibrated, the full distribution model was applied by using AGM. The resulting trip table was then compared with the observed trip table by using several tests. The results of these tests for the work trip purpose are given in Tables 10-12. A primary check on the distribution model was to ascertain if the estimated trips had the same distribution as the observed trips when the impedance measure was highway time or highway distance or both. For the work trip model, this comparison was excellent. Total estimated work trips had an average highway travel time and highway distance that differed from observed trips by less than 0.2 percent. When the average travel time was compared by income level, the results were slightly less accurate but well within normal limits of acceptability. The number of intrazonal trips was also compared, and the results were favorable. Three screen-line checks were made: trips across the Mississippi River, trips across the Navigational Canal, and trips between Orleans Parish and Jefferson Parish. The model overestimated the latter by 1.44 percent, and most of this error was in the lowest income quartile.

The home-based other and non-home-based results are given in Table 13. The average travel time and distance for observed and estimated trips were similar. The model tended to underestimate intrazonal trips, but estimated travel across both major waterways (the Mississippi River and the Navigational Canal) extremely well. However, the movements between Orleans Parish and Jefferson Parish were overestimated.

The income-related sensitivity of the home-based other models to travel time is similar to that of the work models in that low-income travelers are less sensitive than high-income travelers, as shown in Figure 7. However, this sensitivity is less pronounced than for work trips.

Similar models were calibrated for internal-external person trips, taxi vehicle trips, internal-external truck trips, and internal-internal truck trips. They are discussed in the more detailed report on distribution models for New Orleans (15).

Table 10. Final calibration results of home-based work gravity model: average impedance.

	Highway Running Time			Highway Distance			Composite Impedance		
Income Group[a]	Observed	Estimated	Percentage Error	Observed	Estimated	Percentage Error	Observed	Estimated	Percentage Error
1	10.17	10.56	3.83	4.29	4.49	4.66	62.19	62.18	−0.02
2	10.18	10.31	1.28	4.29	4.35	1.40	56.34	56.14	−0.35
3	10.87	10.77	−0.92	4.72	4.68	−0.85	47.17	46.85	−0.68
4	11.16	11.04	−1.08	4.91	4.84	−1.43	38.06	37.85	−0.55
All income groups	10.68	10.70	0.19	4.61	4.62	0.22	48.94	48.73	−0.43

[a]Income groups are divided as follows: 1 = low, 2 = low-middle, 3 = high-middle, and 4 = high.

Table 11. Final calibration results of home-based work gravity model: number of intrazonal trips.

					Intrazonal Trips as a Percentage of Total Trips	
Income Group[a]	Observed	Estimated	Percentage Error	Total Trips	Observed	Estimated
1	936	884	−5.56	61,994	1.51	1.43
2	2,202	2,438	10.72	105,327	2.09	2.31
3	2,895	3,477	20.10	120,191	2.41	2.89
4	3,113	2,906	−6.65	127,533	2.44	2.28
All income groups	9,146	9,705	6.11	415,045	2.20	2.34

[a]Income groups are divided as follows: 1 = low, 2 = low-middle, 3 = high-middle, and 4 = high.

Table 12. Final calibration results of home-based work gravity model: major movement comparison.

Movement	Observed Trips	Estimated Trips	Percentage Error
Across Mississippi River	25,269	26,639	5.42
Across Navigational Canal	38,770	39,985	3.13
Between Orleans and Jefferson Parishes	71,143	72,164	1.44

SUMMARY

A complete set of distribution models was calibrated for the New Orleans region. The original intent of this calibration was to prepare a set of distribution models stratified by income level and using a combined impedance measure that would adequately reflect the travel time and cost of all models. This design proved to be feasible for home-based work trips, thus producing an excellent trip-distribution model. The log sum method of combining impedances yielded better results than the harmonic mean method.

For home-based other and non-home-based trips, the use of a combined impedance measure produced a model that overestimated long trips. For this reason, these models were calibrated by using off-peak highway times. For the home-based work and home-based other distribution models, the income stratification produced F factors that were substantially different by income level, but were logical, in that the higher income strata were more sensitive to travel impedance. The F factors for the non-home-based model showed only minor differences among income strata. In all cases the F factors were calibrated by using the function described in the documentation of program AGM and by using standard statistical regression techniques. A set of K values was required for all models for trip movements across the Mississippi River and the Navigational Canal. The final screen-line checks were quite accurate, with the exception of the home-based other trip movements between Orleans and Jefferson parishes.

With respect to model validation, the results of applying the models to 1980 conditions proved quite satisfying. As reported by Schultz (see paper elsewhere in this Record), the changes between 1960 and 1980 in New Orleans have been substantial. Nonetheless, the 1980 estimates of vehicle miles of travel were within 5 percent of the observed data, which indicate that the distribution (and modal-choice) models performed adequately.

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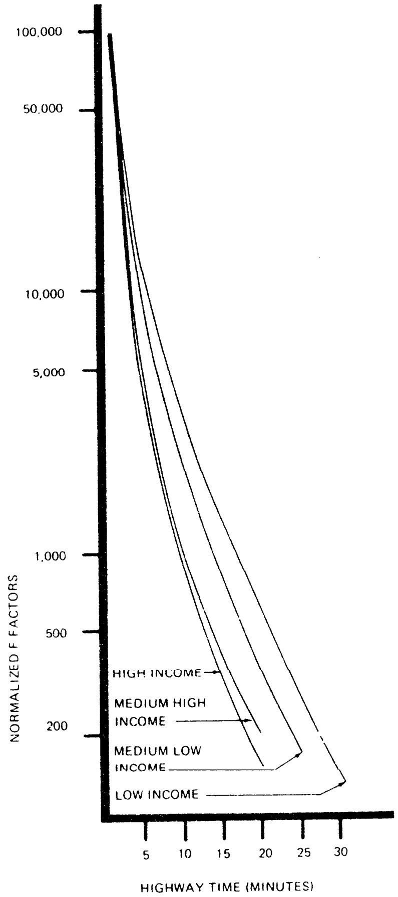
Table 13. Final calibration results of home-based other and non-home-based gravity models.

	Home-Based Other			Non-Home Based		
Measure	Observed	Estimated	Percentage Error	Observed	Estimated	Percentage Error
Highway running time (min)	7.891	7.864	−0.34	7.630	7.642	0.16
Highway distance (mile)	3.186	3.225	1.22	3.089	3.118	0.94
No. of intrazonal trips	90,632	72,593	−19.90	17,827	17,817	−0.06
Major movements						
Across Mississippi River	14,941	15,022	0.54	5,520	5,575	1.00
Across Navigational Canal	39,288	39,515	0.58	7,746	7,825	1.02
Between Orleans and Jefferson Parishes	56,631	68,044	20.15	21,512	23,678	10.07

Figure 7. Home-based other normalized F factors plotted against highway travel time.



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