

Evaluation of Intervening Opportunities Trip Distribution Model

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Methods are presented for calibrating and testing the ability of the intervening opportunities model to simulate present travel patterns to forecast travel patterns for another point in time. Both the calibrating and forecast testing phase of the research, supplemented with necessary background information relating to each phase, as well as the detailed procedures utilized and results obtained (when compared with comprehensive home interview data) are reported. The basic source of data used in the calibration and simulation phase was the 1948 Washington area home interview O-D survey. The calibrated model was then applied to 1955 conditions and resulting trip distribution patterns were checked against the 1955 Washington area home interview survey data to test the forecasting ability of the model. Improved procedures and techniques for calibrating and testing the intervening opportunities trip distribution model are suggested.

•THE INTERVENING opportunities trip distribution model has been used to forecast future travel patterns in several of the larger transportation studies during the past few years. The theory of this model and the general procedures for applying it have been documented to some extent in the literature (1, 2, 3). The use of this model to forecast future travel patterns in several urban areas has also been reported (1, 4). However, there are little published data available to illustrate comprehensively the ability of the intervening opportunities model either to simulate existing travel patterns or forecast future patterns.

The author, together with other personnel from the Urban Planning Division of the U. S. Bureau of Public Roads, has been working on a project to analyze, test, and document the full transportation planning package as developed and programmed originally by the Chicago Area Transportation Study (CATS) (1, 2). The particular phase of the project treated here deals exclusively with the trip distribution portion of this package, herein called the intervening opportunities trip distribution model. This model has also been called the Schneider, Chicago, and the subtended volume trip distribution model. Procedures for applying this model are tested, as well as the accuracy of the model itself in simulating present travel patterns and forecasting future travel patterns in an urban area. In addition, this same project undertook the development of an IBM 7090/7094 computer program for implementing the analytical procedures required. The program was written to utilize input/output which would fit into the Bureau's battery of transportation planning programs.

To test the simulation and forecasting abilities of the model, adequate data on travel patterns for two time periods were required. The Washington, D. C., metropolitan area was chosen because complete and adequate home interview surveys for two separate time periods were available. These data were particularly valuable because similar research, testing other widely used trip distribution procedures, was already com-

pleted (5). Similar research with the same data, providing the first side-by-side comparisons of relative accuracies and advantages of the different techniques, is reported elsewhere (6).

During the summer of 1948, a comprehensive origin-destination (O-D) survey was conducted of 5 percent of the dwelling units in the Washington metropolitan area (7). In 1955 a repeat O-D survey was conducted in the same area (8). Within the District of Columbia, occupants of 3 percent of the dwelling units were interviewed. Elsewhere in the area, occupants of 10 percent of the dwelling units were interviewed. Consequently, the Washington area provided an ideal situation for testing and evaluating the ability of the intervening opportunities model to simulate travel patterns for one period of time and also to forecast such patterns for a different period of time.

This paper describes research on methods for calibrating the intervening opportunities model for a large urban area and for testing the ability of this model to simulate present trip distribution patterns. In addition, it discusses investigations into the ability of this model to predict trip distribution patterns for another point in time. The calibrating and forecast testing phases of the research, supplemented with necessary background information relating to each phase, and the detailed procedures utilized and results obtained (when compared with comprehensive home interview data) are reported in this paper.

INTERVENING OPPORTUNITIES MODEL THEORY

The intervening opportunities trip distribution theory is based on the premise that in urban travel, total travel time from a point is minimized, subject to the condition that every destination has a stated probability of being acceptable if considered. The model states that the probability of a trip that originates in one zone finding a destination in another zone is proportional to the possible trip destinations in the other zone and to the number of trip destinations previously considered:

$$T_{ij} = O_i \left[e^{-LD} - e^{-L(D + D_j)} \right] \quad (1)$$

where

- T_{ij} = trips originating in zone i and destined for zone j ;
- O_i = trip origins in zone i ;
- D = trip destinations considered before zone j ;
- D_j = trip destinations in zone j ;
- L = measure of probability that a random destination will satisfy needs of a particular trip (an empirically derived function describing rate of trip decay with increasing trip destinations and increasing length of trip); and
- e = base of natural logarithms (2.71828).

From this formula, it can be seen that four parameters must be known before T_{ij} can be computed. O_i and D_j are related to the use of land and the socioeconomic characteristics of each zone's traffic-generating population. D_j refers to the number of trips ending in a given zone and O_i refers to the number of trips originating in a given zone, regardless of the zone with which the other end of the trip is associated.

Spatial separation for the intervening opportunities model is measured, not in absolute travel time, time, cost, or distance, but in the number of intervening destinations or opportunities. These intervening destinations or opportunities were determined by time sequencing of possible destination zones from the zone of origin and accumulating the destinations in each of these zones by time sequence. This formula for calculating zone-to-zone movements, as used in previous operational transportation studies,

is an integral part of a larger procedure that also adjusts the transportation network after calculating and assigning trips from each zone. The assumption which has always been made, that this does not significantly alter the ordering of zones or trips calculated between zones, has been verified in work reported by Soltman (9). Therefore, the use of the trip distribution model separately appears reasonable.

The probability factor L is empirically derived and describes the rate of trip decay with increasing trip destinations and increasing length of trip and, as such, gives the trip length distribution for a given network and a given set of trip ends.

Trip origins and destinations for each zone were obtained directly from the home interview O-D survey for both 1948 and 1955. Travel times between zones (skimmed trees) were originally calculated for use in previous research from data collected in the field on the type and extent of the transportation facilities available in the area in 1948 and 1955.

Initial values of L were determined empirically and then adjusted through an iterative process to bring the estimated trip length frequency as close as possible to the survey data.

STUDY AREA

The Washington, D. C., transportation study area is shown in Figure 1. As previously mentioned, comprehensive O-D studies were made in Washington in 1948 and 1955. All phases of these surveys (i. e., internal, external, truck and taxi) used procedures and sample sizes recommended in the U. S. Bureau of Public Roads Manual of Procedures for Home Interview Traffic Study (10). In 1948 data were collected on travel patterns only (7). Information on 1948 transportation facilities, however, was subsequently derived from secondary sources. In addition to 1955 travel data, information was available on the type, extent, and capacity of the transportation facilities in the area, as well as the use of land in the area, in terms of the type and intensity of use. The 1948 data were used to calibrate and test the base year intervening opportunities model, which was then used to forecast trip distribution patterns for 1955.

The cordon lines were located in approximately the same position in 1955 as in 1948. In some areas the 1955 cordon line was extended outward slightly to incorporate new development. Data for both 1948 and 1955 were assigned to 400 internal and 19 external zones. For summary and general analysis purposes, these 419 zones were combined into 47 districts or analysis areas which, in turn, were combined into 9 sectors. District and sector boundaries are shown in Figure 1.

Probably the most significant change in the study area during the 7-year period was the decentralization of many activities of the urban population. Residential, employment, and shopping activities were all relatively less oriented to the central business district (CBD) in 1955 than in 1948 (11).

The total population increased 38 percent, to approximately 1.5 million during the 7-year interval; the number of internal person trips for all purposes increased slightly over 42 percent. The number of autos owned almost doubled, increasing 96 percent. This increase in auto ownership was reflected in the number of auto-driver trips which increased almost 90 percent. Mass transit trips showed a slight decrease in absolute numbers. Several

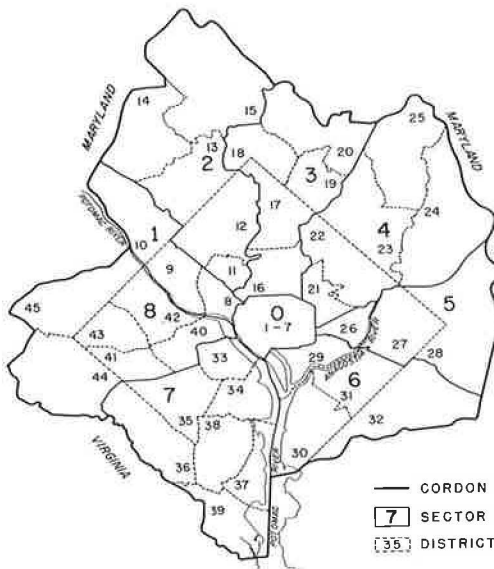


Figure 1. Study area, Washington, D. C., 1948 and 1955.

significant improvements in the transportation system were made during the period between the two surveys, including the additions of the outlying portions of the Shirley Highway, the Spout Run Parkway, the Baltimore-Washington Parkway, and the South Capitol St., East Capitol St., and New York Avenue Bridges.

GENERAL STUDY PROCEDURES

In the use of any trip distribution model, many choices on the manner in which the model will be used are available to the analyst. These choices concern the universe of trips to be used (i. e., peak hour vs total daily trips, person trips vs auto-driver and mass transit trips, total trips in the study area vs trips made only by the residents of the study area, and purpose stratification) and the measure of spatial separation to be used (i. e., driving distance, time or cost vs travel distance, time or cost which includes a measure of terminal time in each zone to account for the congestion involved in parking, and peak hour vs nonpeak hour conditions).

This research project worked with the total daily person trips made by all residents of the area within the cordon line. Total daily trips were used because, in a city as large as Washington, it is desirable to have the total daily patterns rather than a single peak period. Only those trips made by the residents of the study area were used because, among other reasons, the trip length characteristics and the basic reasons for making trips of persons residing within the study area were different from those of persons residing outside but traveling to and from the study area. In addition, the desirability of keeping this research completely comparable to similar research on these same data using other trip distribution procedures was felt important enough to attempt to use person trips in place of auto-driver trips used previously with the intervening opportunities model.

The total travel demands were stratified and used in a number of ways for different research objectives to be discussed later. Both the stratification used previously with the intervening opportunities model and that used previously with other models were tested in this research project. The stratification used in Chicago and other previous applications of the intervening opportunities model is as follows:

Long residential—all home to work trips and trips from home outside the CBD to areas in the CBD for any other purpose;

Long nonresidential—all work to home trips and trips for any other purpose which originate in the CBD and are destined to homes outside the CBD; and

Short—all other trips not counted as long.

The second stratification used in this research has previously been used with the gravity model:

Home-based work—trips between a person's place of residence and his place of employment for the purpose of work;

Home-based shop—trips between a person's place of residence and a commercial establishment for the purpose of shopping;

Home-based social-recreation—trips between a person's place of residence and places of cultural, social, and recreational establishments for social and recreational purposes;

Home-based school—trips, by students, between place of residence and school for the purpose of attending classes;

Home-based miscellaneous—all other trips between a person's place of residence and some form of land use for personal business, medical, dental, and eat-meal purposes; and

Nonhome-based—all trips having neither origin nor destination at home, regardless of the basic trip purpose.

All information from both the 1948 and 1955 travel inventories had previously been verified, coded, and punched into detail trip cards. Trip cards from the home interview survey (No. 2 cards) in both 1948 and 1955 were edited for unacceptable characters and to insure that all pertinent information had been correctly punched. Data

from the external cordon and from the truck and taxi surveys were not considered in this study.

The edited records, originally coded during the home interview survey as "change mode of travel" or "serve passenger" trips, were linked. The need for linking results from the standard home interview definition of a trip, where a single trip may be represented by two or more trip records (i. e., a trip involving change of mode). If each of these trip segments were analyzed separately, the relationships between the actual starting point, the ultimate destination, and the purpose of the trip would be lost. It would also be difficult to relate the type and intensity of land use. By linking trips, approximately 5 percent of the surveyed trip records and an estimated 3 percent of the person-minutes of travel were lost. In both 1948 and 1955 these reductions appeared to be geographically unbiased and, therefore, this linking process was judged to be acceptable.

The edited and linked records for each year, sorted by zone of origin, were then used in the trip table building program to obtain tables of zone-to-zone movements for each of the purpose stratifications outlined. The total number of trip origins and destinations by purpose stratification in each zone was obtained through the summary of trip ends program. These constitute two of the parameters required to calculate trip interchanges by the intervening opportunities model. The zone-to-zone movements were later used as test data in various analyses throughout the calibration of the models.

The travel time between zones used in this research consisted of the off-peak minimum path driving time between zones, obtained from field surveys measuring the geometrics and speed on links in the network, plus estimated terminal time at both ends of the zone-to-zone driving time. Terminal time at both ends of a trip transfer was added to driving time to allow for differences in parking and walking times resulting from congestion and parking conditions in these zones.

Terminal time in the analysis network has not been included in previous uses of this model, but findings of this research indicate that greater accuracy is obtained by its use.

With data from both the 1948 and 1955 surveys now available in the form of zone-to-zone movements by purpose, trip ends by purpose, and transportation networks for both years in terms of travel time between zones, the only other information still needed before calibration of the model was the frequency of trip occurrence by 1-min time intervals for each of the selected trip purpose categories. This was found by combining the travel time between zones with the appropriate zone-to-zone trip transfers. The results were later used in the model calibration procedures.

TABLE 1
DISTRIBUTION OF TOTAL PERSON TRAVEL BY PURPOSE OF TRIP
WASHINGTON, D. C., 1948 AND 1955^a

Trip Purpose	Person Trips				Person-Hours of Travel				Avg. Trip Length (min) ^b	
	1948		1955		1948		1955		1948	1955
	No. ^c	Percent	No. ^c	Percent	No. ^c	Percent	No. ^c	Percent		
Home-based: ^d										
Work	713	43.2	—	—	246	47.8	—	—	20.8	—
Shopping	156	9.5	—	—	41	8.0	—	—	15.6	—
Social-rec.	305	18.5	—	—	91	17.7	—	—	17.9	—
School	73	4.4	—	—	20	3.8	—	—	16.1	—
Miscellaneous	181	11.0	—	—	54	10.5	—	—	17.7	—
Nonhome-based	222	13.4	—	—	63	12.2	—	—	16.9	—
Total	1,650	100.0	—	—	515	100.0	—	—	—	—
Long residential	462	27.8	612	26.1	162	31.2	223	30.8	21.0	21.9
Long nonresidential	441	26.5	581	24.8	155	29.9	212	29.3	21.1	21.8
Short	761	45.7	1,149	49.1	202	38.9	289	39.9	15.9	15.1
Total	1,664	100.0	2,342	100.0	519	100.0	724	100.0	18.7	18.5

^aBased on linked trip figures derived from 1948 and 1955 home interview study.

^bBased on minimum path zone-to-zone travel time.

^cIn thousands.

^dData from 1955 study not included in this research.

When the data were fully assembled, the calibration phase of the research was begun. Several calibration procedures were attempted to determine relative accuracies and ease of application. The total trip universe was first stratified in the two different trip purpose groupings. The resultant trip ends for each of the trip purposes are given in Table 1 for 1948 and 1955.

An attempt was made to calibrate a six-purpose intervening opportunities model using the trip categories as defined and used in previous research in the Washington area with the gravity model (5). The procedure used in this calibration was to obtain a unique L value for each purpose which would result in an estimated mean trip length very closely matching the actual trip length for the appropriate purpose. This approach was evaluated not only from the standpoint of the trip length frequency curves but also for comparison of actual movements and determination of geographic bias.

The next approach used the three purposes as recommended by previous users of this model but with slightly different calibration procedures than previously used.¹ Each purpose was calibrated separately as outlined, with L values adjusted until each purpose model reproduced the average trip length for that particular purpose category of trips. Again the trip length frequency curves, as well as selected estimated movements, were examined.

The third approach utilized the same input trip ends in three categories as the second approach. The procedures used to calibrate this model also closely matched those as developed and used previously with the intervening opportunities model. The output by purpose was used only as information assisting in the calibration of a total purpose model. In adjusting the L values by trip category, no attempt was made to make this purpose estimated average trip length match that of this unique set of trips. Instead, each L was adjusted to bring not only the average trip length but also the trip length frequency curve of the total purpose model into agreement with the total purpose O-D information. Selected movements were examined with the output of the total purpose model using these procedures.

The best approach was selected and used to obtain a final calibrated model for the 1948 Washington, D. C., area. With this model, selected adjustments were made to the final 1948 L values to bring them into focus on 1955 conditions. This was done as nearly as possible as it would have to be done in an operational transportation study. All of the information which could be gleaned from the literature was used to make these adjustments. The actual trip end data from the 1955 survey were used in making these adjustments, as well as in the actual forecast runs of the model. The interest of this research was trip distribution procedures, not trip end estimating procedures; therefore, the ability to forecast trip ends perfectly was assumed.

Thus, the model was used to forecast travel patterns for the 1955 study area, using procedures evolved from the best 1948 calibration runs and input data consisting of these adjusted L values, trip origins and destinations from the 1955 survey, and travel times from the 1955 transportation system. The resulting travel patterns were rigorously tested by comparison to the actual data from the 1955 survey.

CALIBRATION OF 1948 INTERVENING OPPORTUNITIES MODEL

One problem involved in using the formula for the intervening opportunities model (Eq. 1) is the lack of a built-in process to insure that all the trips will be distributed. For a given set of trip destinations in a study area, any particular L value used in the formula will determine the number of trips sent from any zone. The percentage of trips that will actually be sent from a particular zone with a given L and number of trip destinations can be calculated by solving Eq. 1. By summing both sides for all destination zones j, we have

¹The intervening opportunities trip distribution model has been used in transportation studies in Chicago, Pittsburgh, Upstate New York and other areas, with generally the same approach. Throughout this paper, mention of previous users of this model is meant to be a general reference to those previous studies unless specified otherwise.

$$\sum_{j=1}^n T_{ij} = O_i \sum_{j=1}^n \left[e^{-LD} e^{-L} (D + D_j) \right] \quad (2)$$

Dividing by O_i yields the trips actually distributed from zone i , $\sum_{j=1}^n T_{ij}$, over those available to be sent, O_i , on the left side. Next, with expansion of the right side of the equation, $\sum_{j=1}^n \left[e^{-LD} e^{-L} (D + D_j) \right]$, most of the terms cancel each other, leaving only $1 - e^{-L} \sum_{j=1}^n D_j$. The $\sum_{j=1}^n D_j$ is nothing more than the total study area destinations which are known. Thus, by setting $100 \times \frac{\sum_{j=1}^n T_{ij}}{O_i}$ or the percent of trips sent at 98 or any desired level, the required L can be calculated.

However, an L value so calculated to assure sending the correct number of trips may not provide a satisfactory trip length frequency distribution, as determined from numerous runs using this model with varying L values. These runs indicated that the same ratio of trips actually sent over those available exist at the zone level as well as in the entire study area. If a particular zone was sending 70 percent of the trips available to it, then this percentage would be the same for every other zone and, therefore, for the entire study area. This is to say that the analysis outlined above for zone i can be applied for all zones. Furthermore, these same applications indicated that each receiving zone was also low by approximately the same amount. Thus, by adjusting each of the probability terms in the model $\left[e^{-LD} e^{-L} (D + D_j) \right]$ by the same appropriate factor, the correct number of trips would be sent from each zone and, therefore, for the entire study area. This factor can be easily calculated and for ease of operation was applied to the O_i for each zone rather than individually to each of the $\left[e^{-LD} e^{-L} (D + D_j) \right]$ terms, since the results would be the same. This adjustment has been added to the original procedures and incorporated into the U.S. Bureau of Public Roads program used throughout this research project. Its use in the BPR program is optional.

As noted previously, this project used only trips internal to the study area. Obviously, if more area is included in the analysis, more destinations will be added and less of a problem will exist in sending out all the trips. Previous uses of this model have employed the externally surveyed trips as well as measures of trip destinations for population centers somewhat removed from the immediate study area. Another objective of this research was to determine if procedures could be developed to work within a relatively closed study area.

With this revised program, the basic calibration of the 1948 model was undertaken. The first approach was to attempt to build six separate models using trip categories used previously with the gravity model and summarized in Table 1. Trip ends for these six purposes and the 1948 transportation system have already been discussed, and all that is needed to apply the model are L values.

The L values determine, for a given network and set of trip ends, the trip length distribution. Early uses of the intervening opportunities model required deriving the L factors empirically. Two such factors were required in most studies, one for the long trips and one for the short trips. The Pittsburgh Area Transportation Study developed an L value for each zone for both long and short trips (4).

Experience in several studies has allowed the development of procedures to obtain realistic first estimates of L factors. To obtain an estimated long L, two methods were used.

First Method (3)

$$\frac{\bar{r}_1}{\bar{r}_2} = \frac{\sqrt{L_2 P_2}}{\sqrt{L_1 P_1}} \quad (3)$$

where

- \bar{r}_1, \bar{r}_2 = average trip length in miles for cases 1 and 2 where the first case is from a city where the model has already been calibrated;
- L_1, L_2 = L values for cases 1 and 2 (L_1 already known); and
- P_1, P_2 = trip ends per square mile.

Second Method (13)

$$\bar{r} = K \sqrt{\frac{1}{PL}} \quad (4)$$

where

- \bar{r} = average trip length in miles;
- K = proportionality constant approximately equal to $\sqrt{2\pi}$;
- P = density of study area expressed as trip ends per square mile; and
- L = probability of trip termination described earlier.

In the applications reported here, the second method, with slightly revised input, was used to obtain the initial values of L for each of the six trip purposes. The first method requires data from a previously calibrated model for another city which was not available to us for the six-purpose model application. Also, it should be pointed out that in this case it was more desirable to work with the average trip length in minutes instead of miles. If miles were to be obtained, the output of the distribution program would require assignment to the transportation network to obtain average trip length in miles. Without this requirement, the distribution model calibration can be accomplished separately and assignments could await the development of sound zone-to-zone movements.

Information determined from the 1948 Washington, D. C., study results was inserted into the second equation using average trip length in minutes rather than miles and initial values of L calculated for each of the six purposes as follows:

- Home-based work, 2.37×10^{-6} ;
- Home-based shop, 19.22×10^{-6} ;
- Home-based soc.-rec., 7.49×10^{-6} ;
- Home-based school, 38.64×10^{-6} ;
- Home-based other, 12.84×10^{-6} ; and
- Nonhome-based, 11.49×10^{-6} .

These L values were used with the appropriate trip ends and six models were built. The resulting output, in the form of average trip length and trip length frequency curves by purpose were compared to like information from the O-D survey (Table 1). Several runs were required for each purpose, adjusting L each time, before the average trip length of the estimated trips closely matched that from the survey. Table 2 summarizes selected information from the initial and final runs of this model for each purpose. The information in this table, when compared with similar informa-

TABLE 2

SUMMARY INFORMATION FROM INITIAL AND FINAL RUNS, SIX-PURPOSE INTERVENING OPPORTUNITIES MODEL, WASHINGTON, D. C., 1948

Trip Purpose	Person Trips (×1,000)	Initial Run			Final Run				
		Person-Hours of Travel (×1,000)	Avg. Trip Length ^a (min)	No. of Intras	L Value (×10 ⁻⁶)	Person-Hours of Travel (×1,000)	Avg. Trip Length (min)	No. of Intras	L Value (×10 ⁻⁶)
Home-based:									
Work	713	251	21.1	3,378	2.37	246	20.7	3,801	2.85
Shopping	156	54	20.7	1,505	19.22	41	15.6	4,741	67.13
Social-rec.	305	107	21.0	2,998	7.49	91	17.8	5,829	16.16
School	73	24	19.5	815	38.64	19	16.1	1,805	93.65
Miscellaneous	181	62	20.7	1,492	12.84	53	17.6	3,103	21.50
Nonhome-based	222	69	18.6	5,287	11.49	62	16.8	8,641	15.76

^aBased on minimum path zone-to-zone travel time.

tion from the O-D survey given in Table 1, indicates that the use of the six-purpose models allows the analyst to build a model which will duplicate the average trip length by purpose. However, the total number of intras (trips remaining in a zone) are underestimated by approximately 55 percent. By examining the trip length frequency curves plotted at 1-min travel time increments, it was apparent that satisfactory frequency curves could not be obtained with these procedures. Work and nonhome-based trip categories did fairly well. The work trip length frequency curve for the final model is shown plotted against the O-D data in Figure 2. However, when all purposes are combined, the total purpose trip length frequency indicates a very inadequate duplication of the O-D survey data. This can be seen by examining Figure 3.

Two other tests were made on the final work trip model to determine the accuracy of selected estimated movements. Figure 4 shows a comparison of the predicted movements against the O-D movements to the CBD for work trips and Table 3 gives a comparison of estimated to actual work trips crossing the Potomac and Anacostia Rivers. Both of these tests indicate that the model is simulating travel patterns fairly well; however, because of the inability to simulate the trip length frequency by 1-min increments satisfactorily for all purposes, the procedure using six separate purpose models, each with a unique L value, was deemed unsatisfactory.

The second approach used to calibrate the intervening opportunities model used similar reasoning and procedures as the first, but total trips were stratified according to the second group summarized in Table 1, namely, long residential, long nonresidential, and short. Using trip ends stratified into these trip categories and long and short L values of 3.11×10^{-6} and 5.60×10^{-6} , respectively, calculated using Eq. 4, the first estimate of travel patterns was obtained. Several runs were again made to obtain an L which, when applied, would give an average trip length closely matching that

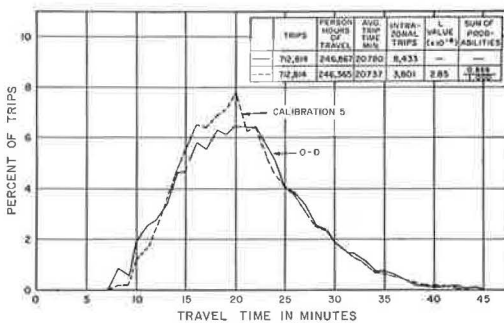


Figure 2. Comparison of trip length distribution (OD vs model), work trips, Washington, D. C., 1948.

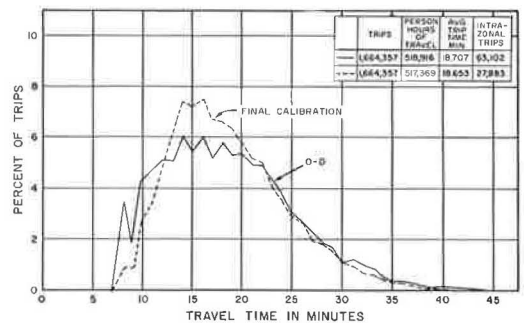


Figure 3. Comparison of trip length distribution (OD vs model), total trips, six-purpose model, Washington, D. C., 1948.

TABLE 3
COMPARISON OF TRIPS CROSSING POTOMAC AND ANACOSTIA RIVERS, HOME INTERVIEW SURVEY VS INTERVENING OPPORTUNITIES MODEL,
WASHINGTON, D. C., 1948

Calibration	Trip Purpose	Potomac River						Anacostia River					
		Orig. in Va. (× 1,000)		Diff. ^a (%)	Orig. in Md. & D. C. (× 1,000)		Diff. ^a (%)	Orig. South of River (× 1,000)		Diff. ^a (%)	Orig. North of River (× 1,000)		Diff. ^a (%)
		Survey	Model		Survey	Model		Survey	Model		Survey	Model	
(a) Work Trip Model													
5	Home to work	70	90	+29	44	39	-12	83	90	+ 8	16	13	- 8
(b) Three-Purpose Model													
4	Long residential	52	63	+21	23	20	-12	57	61	+ 6	9	7	-24
	Long nonresidential	22	34	+55	50	54	+ 8	8	12	+49	54	43	-21
	Short	25	47	+91	25	18	-30	26	40	+53	29	15	-47
5	Long residential	52	57	+10	23	29	+27	57	59	+ 2	9	11	+25
	Long nonresidential	22	33	+49	50	61	+23	8	11	+36	54	57	+ 4
	Short	25	32	+30	25	23	- 7	26	28	+ 7	29	24	-18
(c)													
7	Total	98	114	+15	98	127	+29	92	92	0	92	105	+14
8	Total	98	103	+ 4	98	85	-13	92	95	+ 3	92	99	+ 8

^aComputed before rounding.

TABLE 5
FREQUENCY DISTRIBUTION A:
DIFFERENCES, SHORT TRIPS,
WASHINGTON, D. C.

Volume Group	Frequency	Mean V _i
		OD
0- 499	61	273
500- 999	65	753
1,000-1,499	47	1,245
1,500-1,999	40	1,687
2,000-2,499	27	2,217
2,500-2,999	26	2,744
3,000-3,499	25	3,235
3,500-3,999	18	3,712
4,000-4,499	18	4,251
4,500-4,999	7	4,798
5,000 +	26	6,947

^aTrips received by zone, O-D vs interv

$$D_j \left(\sum_{i=1}^n \right)$$

This procedure was to effect and then was incorporated bring the trips received number of iterations to a

FREQUENCY DISTRIBUTION
INTERVENING

Trip Purpose	Volume Group
Long residential	0- 499
	500- 999
	1,000- 1,999
	2,000- 2,999
	3,000- 3,999
	4,000- 4,999
	5,000- 5,999
	6,000- 7,999
	8,000- 9,999
	10,000-14,999
Long nonresidential	0- 499
	500- 999
	1,000- 1,999
	2,000- 2,999
	3,000- 3,999
	4,000- 4,999
	5,000- 5,999
	6,000- 7,999
	8,000- 9,999
	10,000-14,999
Short	0- 499
	500- 999
	1,000- 1,999
	2,000- 2,999
	3,000- 3,999
	4,000- 4,999
	5,000- 5,999
	6,000- 7,999
	8,000- 9,999
	10,000-14,999
15,000-19,999	

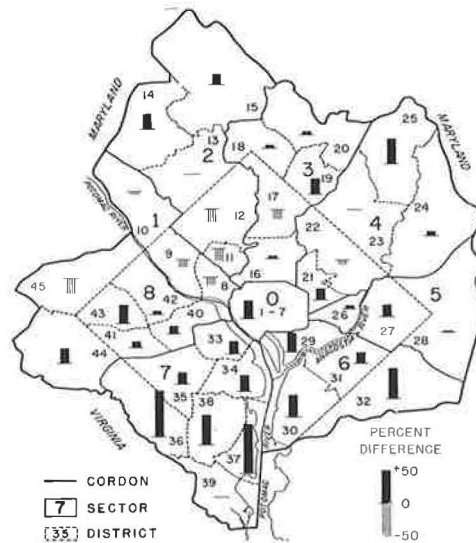


Figure 4. Comparison of work trips to zero sector, home-based work model, calibration 5, Washington, D. C., 1948.

Trips estimated by the model from each district to the CBD were examined and compared to the actual patterns. This comparison is shown on Figure 8. When compared to the O-D data, almost every district showed an overestimate of travel predicted by the model to this central part of the city; the average overestimate was 20 percent. Of course, with such a poor comparison within the CBD, other parts of the study area would necessarily have fewer trips ending than desired. A comparison of trips esti-

from the appropriate trip category of the actual survey trips. Table 4 summarizes each of these runs. This desired objective was accomplished with two adjustments in L values for the long categories and three for the short trips. Selected information from these runs is shown on Figures 5 through 7, along with the initial and last estimate of trip length frequency. Again, it can be seen that the trip length frequency curves are not necessarily in close agreement with the O-D curve just because the average trip length is close. The curves for the long categories were in fairly close agreement, but the short category exhibited significant bias in some portions of the curve. As was the case with the six-purpose model, the intrazonal trips were considerably underestimated.

With the average trip length in agreement by purpose and, therefore, by total, but with known inadequacies in the number of intrazonal trips and the predicted trip length frequency curves, additional tests were made to examine more directly the trip movements as predicted by the model.

TABLE 4

SUMMARY INFORMATION FOR CALIBRATION OF THREE-PURPOSE INTERVENING OPPORTUNITIES MODEL, WASHINGTON, D. C., 1948

Trip Purpose	Run No.	Total Trips ($\times 1,000$)	Person-Hours of Travel ($\times 1,000$)	Avg. Trip Length ^a (min)	Intratrips	L Value ($\times 10^{-6}$)
Long residential	O-D	462	162	21.0	4,369	—
	1	462	165	21.4	1,780	3.11
	2	462	164	21.3	1,806	3.23
	3	462	162	21.0	2,042	3.88
Long nonresidential	O-D	441	155	21.1	4,117	—
	1	441	154	21.0	1,646	3.11
	2	441	154	21.0	1,646	3.08
	3	441	155	21.1	1,618	2.96
Short	O-D	761	202	15.9	54,616	—
	1	761	232	18.3	16,160	5.60
	2	761	217	17.1	20,983	7.38
	3	761	206	16.3	25,572	9.05
	4	761	203	16.0	27,494	9.75

^aBased on minimum path zone-to-zone travel time.

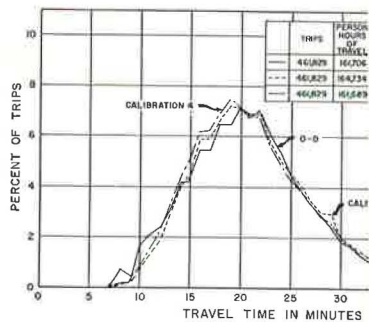


Figure 5. Comparison of trip distribution (OD vs model), long trips, Washington, D. C.,

mated to arrive at each zone in the O-D survey. A statistical are given for short trips in Ta approximately the same for ea

To complete the analysis of mated movements across the known movements crossing the dicate very strongly the same does the previously discussed by the overestimate of trips in each river.

To document the accuracy c process, both the estimated ar district-to-district interchange of this analysis by volume gro

After establishing the stron trips received by zone, proced be incorporated to insure that in the study area received appr the correct number of trips. ment should correct the overes trips to the CBD and, at least the river crossing bias.

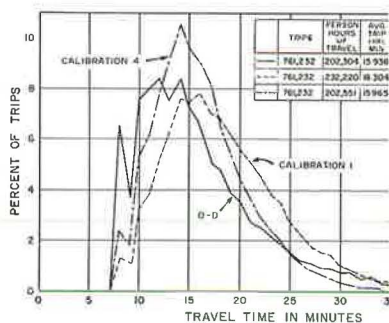


Figure 7. Comparison of trip distribution (OD vs model) short trips, Washington, D. C., 1948.

An additional calibration run was made using the same input data as the one just discussed, but allowing the destinations to be adjusted by one iteration. This run was analyzed in much the same manner as the previous one to determine the effect of balancing the destinations. The results showed that the estimated total average trip length was increased to 18.924 min from 18.714 min. The trip length frequency curve was improved somewhat but still exhibited significantly different characteristics than the survey data. Of course, the trips sent and received by each zone were in approximate balance as designed.

Trips estimated by the model from each district to the CBD are compared in Figure 9 to the actual movements. This comparison shows a considerable improvement in these movements using the balanced trip destinations in the model. Table 3 indicates very little improvement in the total number of trips estimated to cross these two rivers. The assumption that the overestimate of river crossings would be substantially improved was, therefore, shown to be wrong.

Finally, the estimated zone-to-zone interchanges were compressed and compared statistically to the survey data (Table 6). When these results are compared with the results from calibration 4 (Table 6), the increased accuracy in the district-to-district movements brought about by balancing the destinations can be seen.

The procedures just discussed for calibrating the intervening opportunities model were rejected for much the same reasons as the first set of procedures. By attempting to develop a unique L value for each purpose of trip (long residential, long nonresidential and short) which will simulate the average trip length for the same group of survey trips, problems are encountered in other tests made on the model. The most basic problem is that even though the average trip lengths are in close agreement, the trip length frequencies do not exhibit close agreement.

Because of this problem, a third approach, very similar to that used in many previous applications of the intervening opportunities model, was tried. First, trip ends are stratified into long residential, long nonresidential and short categories. Next an L for short trips is estimated which will provide output giving approximately the correct number of intrazonal trips. Finally, one single L value for the long trips is chosen which, when applied to the two subcategories of long trip ends and combined with the short trips, will add up to a satisfactory duplication of the total purpose trip length frequency curve and average trip length.

With these procedures in mind, new L's were estimated by examining, first of all, the short L needed to send out the correct number of intrazonal trips. Next, an estimate of the person-hours of travel which such a short L would contribute was estimated by examining previous runs of the short trip category. This was subtracted from the total person-hours desired and a long L was estimated, again from previous runs which would combine to provide the desired total purpose hours of travel. These L values were estimated to be 17.0×10^{-6} for the short category and 0.5×10^{-6} for the long category.

With these revised L values and the trip ends broken down into long residential, long nonresidential and short, the model was run again. The total estimated intrazonal trips of 52,194 compare much more favorably with the survey intrazonal trips of 63,102 than do any previous runs. The total purpose estimated average trip length

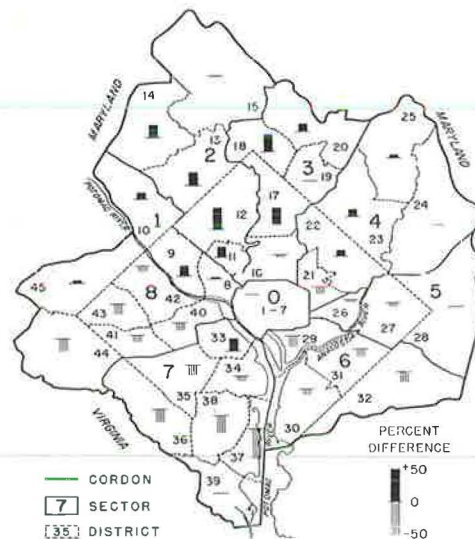


Figure 9. Comparison of total trips to zero sector, three-purpose model, calibration 5, balanced destinations, Washington, D. C., 1948.

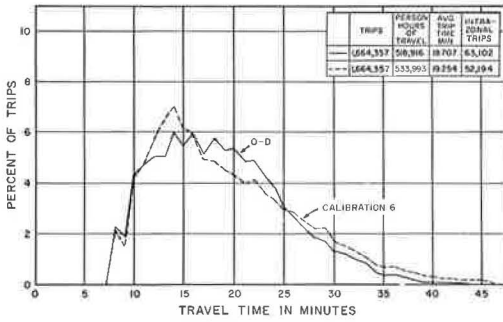


Figure 10. Comparison of trip length distribution (OD vs model), total trips, Washington, D. C., 1948.

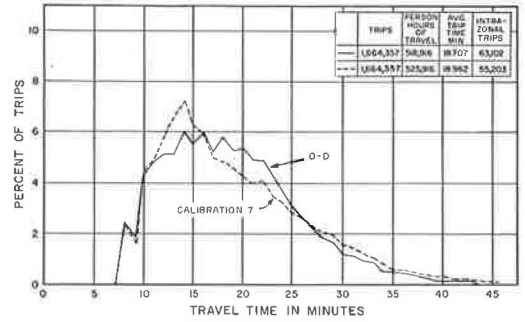


Figure 11. Comparison of trip length distribution (OD vs model), total trips, Washington, D. C., 1948.

of 19.254 min was slightly greater than the 18.707 min from the survey. The information showing estimated vs actual trips by trip-length for the total purpose is shown in Figure 10.

This output was examined very closely and each L value was adjusted to bring the model results in terms of average trip length and the trip length frequency curve for total purpose trips into closer agreement with the desired objectives. Those revised L values are 18.0×10^{-6} for short trips and 1.0×10^{-6} for long trips.

The revised L values were used to obtain a new estimate of travel patterns for the study area. This time, 55,203 intrazonal trips were predicted as compared to the desired total of 63,102. The new average total purpose trip length of 18.962 min was also much closer to the desired 18.707 min from the survey.

Information showing trips estimated vs trips from the O-D survey by trip length is shown in Figure 11 for total trips. Some parts of this curve have been improved and other parts have decreased in accuracy when compared to the actual survey data.

A full set of tests was run on the output of this particular application of the model. Total purpose trips estimated from each district as compared with the O-D survey data to the CBD are shown in Figure 12. Although almost every district to CBD movement is underestimated, the results agree fairly well with actual data.

Table 3 indicates that problems still exist in predicting the correct number of trips crossing the Potomac River, but there is no problem with the Anacostia crossings.

As in previous runs of the model, the estimated zone-to-zone trip transfers were compressed to district-to-district tables and compared statistically to similar information from the O-D survey. The results are given in Table 7. Since the method being used to calibrate the model in this run was directed at satisfactory simulation of the total purpose travel patterns only, the comparison is for total purpose.

Examination of the various tests made on this output shows two problem areas. The first can be seen by comparing the

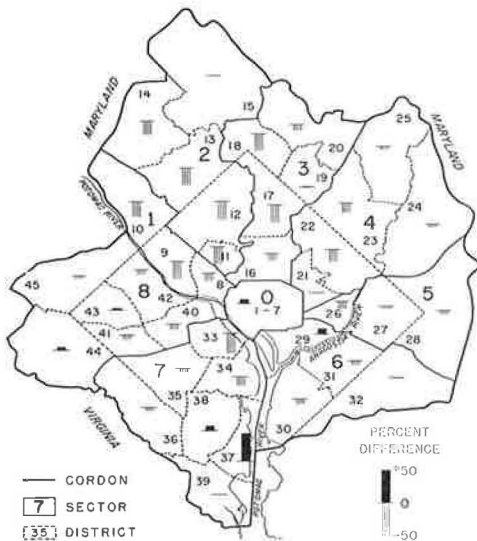


Figure 12. Comparison of total trips to zero sector, total purpose model, calibration 7, Washington, D. C., 1948.

TABLE 7

FREQUENCY DISTRIBUTION AND ANALYSIS OF DIFFERENCES, TOTAL PURPOSE, DISTRICT MOVEMENTS, O-D VS INTERVENING OPPORTUNITIES MODEL, WASHINGTON, D. C., 1948

Volume Group	Frequency	O-D Mean Volume	Calibration 7				Calibration 8			
			Model Mean Volume	RMS Error		Model Mean Volume	RMS Error			
				Abs.	Percent		Abs.	Percent		
0- 499	1,066	174.33	229.65	147.69	84.72	212.74	139.67	80.12		
500- 999	257	711.55	755.66	275.02	38.65	750.72	323.94	45.53		
1,000- 1,999	203	1,414.45	1,404.33	460.53	32.56	1,437.68	485.60	34.31		
2,000- 2,999	78	2,574.65	2,267.94	761.77	29.59	2,403.04	792.21	30.77		
3,000- 3,999	59	3,423.56	3,099.20	940.15	27.46	3,219.47	966.46	28.23		
4,000- 4,999	29	4,425.83	4,495.03	1,320.88	29.84	4,812.66	1,261.42	28.50		
5,000- 5,999	14	5,352.43	4,898.07	1,493.25	27.90	5,205.86	1,491.16	27.86		
6,000- 7,999	9	6,541.44	7,317.89	2,718.33	41.56	7,042.11	1,986.34	30.36		
8,000- 9,999	11	9,287.64	7,851.64	2,508.32	27.01	8,078.18	2,789.98	30.04		
10,000-14,999	10	12,114.80	9,662.30	2,805.49	23.16	8,871.70	3,878.95	32.02		
15,000-49,999	6	20,040.05	20,755.67	3,912.93	19.53	19,354.83	2,871.91	14.33		

information on Figure 11 to that on Figure 10. Even though the use of a higher L value for the short trips in the latter run brought the intrazonal trips into closer agreement, it also had a detrimental effect on the trip length frequency curve by raising the peak so as to make the first portion of that curve worse. However, the increase of the long L values improved the curve in the range of 15 to 50 min. It is apparent that some compromise must be made between the number of intrazonal trips estimated and the trip length frequency. Because intrazonal trips vary by zone size, it appeared more reasonable to place greater emphasis on the trip length frequency.

In addition, to attempt to correct the bias in the estimated Potomac River crossings, a value of 5 min was added to all network links crossing this physical barrier to free travel. This procedure has also been found necessary in applying the gravity trip distribution model to the Washington area (5).

The results of these adjustments showed significant improvements in several key parameters of the model output. First, the total purpose trip length frequency curve showed improvement in the peak range of trip occurrence around 15 min brought about by reducing the L value for short trips. Next, the curve was improved in all times greater than 15 min resulting from the increased value of the long L. As was expected, that portion of the curve prior to 10 min was reduced in accuracy as the short L value was decreased. The average trip length of 19.419 min as predicted by the use of these L values compares quite favorably with the survey information of 19.297 min. Both the survey and model information reflects the use of the 5-min barrier. As expected, the intrazonal estimated trips were decreased to 41,834. This information is shown on Figure 13.

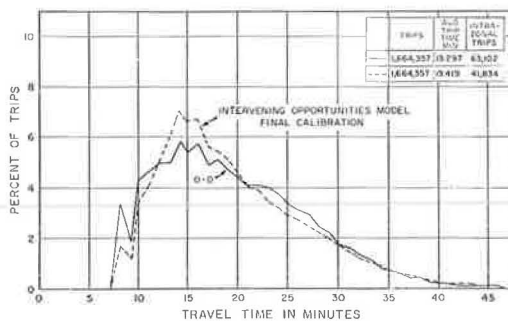


Figure 13. Comparison of trip length distribution (OD vs model), total trips, Washington, D. C., 1948.

Table 3 illustrates that with the use of the 5-min time barrier the problem of overestimating trips across the Potomac River is eliminated. Figure 14 shows a comparison of trips estimated from each district to the CBD to those known to make these movements from the O-D survey. This comparison indicates no strong geographical bias in model results.

Examination of the output from this run shows that the model is very close to the original goals of the calibration process. The average trip length for the estimated total trips is very close to that for the surveyed trips. Likewise, the trip length frequency curve of estimated total person

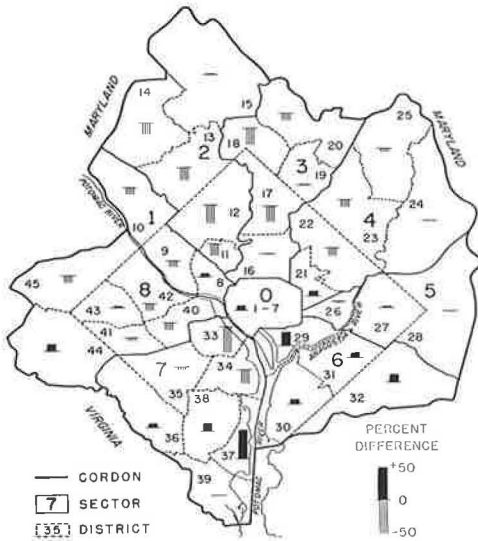


Figure 14. Comparison of total trips to zero sector, total purpose model, calibration 8, Washington, D. C., 1948.

trips is in closer agreement with the O-D survey data using this set of L values than with any previous runs of the model. Some thought was given to adjusting the L values again in an attempt to bring the model results closer. The peak of the travel occurrence could be reduced somewhat, but the number of intras would be further underestimated along with trips occurring from time 0 to 14 min in the trip length frequency curve. The use of the 13.0×10^{-6} and 2.5×10^{-6} L values gave results which come close to matching the 1948 travel patterns. Some compromise in accuracy must be made between the various parameters tested when using only two values of L.

By using a 5-min time barrier in the transportation network, a satisfactory estimate of trips crossing the two rivers was obtained.

The total purpose trip tables were compressed to district-to-district tables and compared statistically with the same information from the O-D survey. Results of this test are shown in Table 7 and in-

dicade that the model was satisfactorily duplicating the survey data.

Out of the several calibration runs of the model, using the six-purpose and three-purpose trip ends and the three sets of calibration procedures, calibration 8 proved to be the best. This particular calibration has just been described. With this final model calibrated for 1948 conditions, necessary changes in the final L values could be made and the model applied to 1955 trip ends and transportation system to test the forecasting ability of the model.

FORECASTING 1955 TRAVEL PATTERNS

The next phase of the research was the forecasting of travel patterns for the 1955 Washington area. Trip ends were available for each zone for the three categories of trips. Likewise, the 1955 transportation network was available. The final 1948 L values required adjustment to fit the 1955 conditions. To do this, maximum use was made of published information on the procedure by previous users (1, 3, 4). It is well accepted that as the number of trips increase, L values should be reduced. Specifically, adjustments to obtain 1955 L values were made relying heavily on the procedures and reasoning used by CATS (1, p. 88).

The long L value for 1948 of 2.5×10^{-6} was adjusted by a factor of $1/1.4 \times 1/2$ to a value of 1.65×10^{-6} for 1955 conditions. This is the ratio of present trips to future trips multiplied by $1/2$. Since there is an increase of 40 percent in the number of opportunities or destinations in the study area, it is apparent that the probability that any one destination will be acceptable to a particular origin will be reduced. The reduction in this case made in the 1948 L values to bring them into focus for the 1955 conditions was made following the CATS procedures (1).

The CATS final report suggests that the relationship of present short L value times present number of intrazonal trips equal to future short L value times future number of intrazonal trips can be used to calculate the future short L value. Thus, by knowing the future number of intrazonal trips, the future short L value may be obtained.

However, the number of intrazonal trips increased over 100 percent from 1948 to 1955 and, therefore, the recommended relationship of short L (1948) times volume of intrazonal trips (1948) equal to short L (1955) times volume of intrazonal trips (1955)

did not appear reasonable, since this would reduce the 1955 L value for the short trips by over 50 percent.

The L value for short trips for 1955 was obtained by reducing the 1948 short L by 17 percent or half of the reduction for the long L value. This gave an answer of 10.80×10^{-6} for the 1955 short L value. This reduction was in about the same relationship to the reduction in the long L value as that made in Chicago (1).

These estimated 1955 L values, along with the appropriate 1955 trip ends and 1955 transportation system, revised to include the same 5-min time barrier on Potomac River crossings, were used in the model to forecast travel patterns for 1955.

The first information checked was the agreement of the trips received by zone as predicted by the model to those which were known to have been received by zone in the survey data and were coded as destinations in the first run. Again, as found in calibration 4, the CBD zones were all high in number of trips received. The total trips received by the CBD as estimated by the model was 51 percent too high. Therefore, the 1955 destinations were adjusted as outlined previously for the 1948 calibration 4 and the model was rerun using exactly the same input data with the adjusted destinations coded by zone.

The output for the total purpose trip length frequency is plotted with the actual trip length from the survey trips in Figure 15. The results show comparatively good agreement of the forecasted with the actual patterns when evaluated from a trip length frequency standpoint. The forecasted average trip length of 20.262 min is slightly over 1 min greater than the actual average trip length of 19.073 min from the surveyed travel patterns. Depending on the ability to forecast the average trip length accurately, either in time or distance, adjustment of the two L values might be in order if this forecast were being done in an operational study. The forecasting of such parameters is the subject of much interest and research at the present time. There did not appear to be sufficient evidence regarding trip length changes or trends to justify a correction in the forecast from the results obtained.

Trips estimated to the CBD were isolated and are compared to the actual movements in 1955 in Figure 16. The accuracy of these forecasts compares favorably with the same comparisons made with the final 1948 calibration run, shown in Figure 14.

As was done for 1948, the estimated and actual zone-to-zone movements were compressed to district-to-district movements and compared. This comparison was done by volume group and the results are given in Table 8. These results show, as would be expected, that the errors are slightly greater for the 1955 forecast comparisons than for the 1948 calibration comparison.

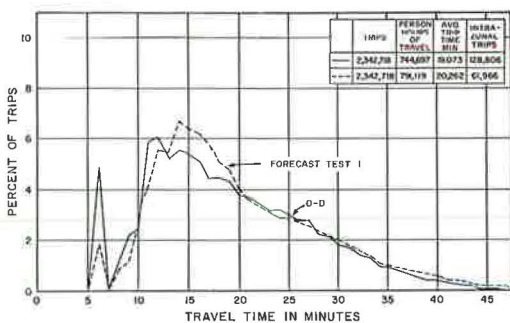


Figure 15. Comparison of trip length distribution (OD vs model), total trips, Washington, D. C., 1955.

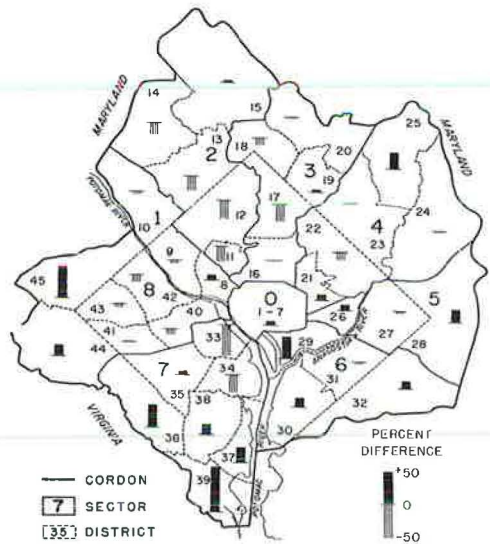


Figure 16. Comparison of total trips to zero sector, forecast 1, 5-min time barrier, Washington, D. C., 1955.

TABLE 8

FREQUENCY DISTRIBUTION AND ANALYSIS OF DIFFERENCE, TOTAL PURPOSE, DISTRICT MOVEMENTS, O-D VS INTERVENING OPPORTUNITIES MODEL, WASHINGTON, D. C., 1955

Volume Group	Frequency	Forecast 1 ^a				Forecast 2 ^b			
		Mean Volume		RMS Error		Mean Volume		RMS Error	
		Survey	Model	Abs.	Percent	Survey	Model	Abs.	Percent
0- 499	1,042	185.56	273.06	159.83	86.58	184.60	272.19	138.77	75.17
500- 999	356	732.78	842.01	340.78	46.50	732.78	844.19	346.35	47.27
1,000- 1,999	251	1,406.84	1,504.77	547.71	38.93	1,406.84	1,501.97	553.94	39.37
2,000- 2,999	126	2,416.34	2,669.71	887.72	36.74	2,416.34	2,670.18	888.75	36.78
3,000- 3,999	77	3,489.47	3,388.36	954.15	27.34	3,489.47	3,390.26	963.89	27.62
4,000- 4,999	43	4,429.81	4,409.60	1,429.92	32.28	4,429.81	4,418.65	1,424.46	32.16
5,000- 5,999	15	5,547.20	5,416.53	880.42	15.87	5,547.20	5,416.87	877.28	15.81
6,000- 7,999	17	6,742.06	5,581.53	2,298.20	34.09	6,742.06	5,588.88	2,297.78	34.08
8,000- 9,999	12	8,725.83	7,845.75	2,219.38	25.43	8,725.83	7,855.58	2,209.69	25.32
10,000-14,999	12	11,983.92	8,132.83	4,632.03	38.65	11,983.92	8,132.33	4,632.63	38.66
15,000-49,999	15	21,760.53	14,847.67	7,533.21	34.62	21,760.53	14,846.69	7,534.10	34.62

^aUsing 5-min barrier.

^bUsing 8-min barrier.

Finally, the river crossings as estimated by the model are compared to the actual crossings for 1955 in Table 9. Even with the use of the 5-min barrier on those links crossing the Potomac, the model overpredicted trip crossings by 22 percent.

Past research showed the need for the same type of barrier for the gravity model and, in addition, showed a quantity of barrier needed in 1955 different from that needed in 1948. The results indicated that the same might also be true with the intervening opportunities model. Using the same procedures as developed in earlier gravity model research, the required adjustment was made by assuming a direct relationship between congestion level for the 2 years and the required time barriers for each time period (5). The volume-to-capacity ratios for both periods were already known, as well as the time barriers required by the intervening opportunities model in 1948. Using this information, a revised time barrier of 8 min for 1955 was established. The transportation system input was updated to reflect the change and the model was run again with otherwise unchanged input data.

The predicted output for the total purpose trip length frequency based on an 8-min time penalty for river crossings is plotted with actual trip length in Figure 17. There is little change in the degree of agreement of these two curves from the previous run shown in Figure 15. The forecasted average trip length of 20.639 min compares with the actual average trip length of 19.388 min. Both the model and survey data include the effect of the 8-min time barrier.

Trips estimated to the CBD were isolated and are compared in Figure 18 to the actual movements in 1955. The improvement made by including the extra 3-min time barrier can be seen by comparing this figure with Figure 16.

Table 9 indicates that the use of the 8-min time barrier improved the ability of the model accurately to reflect trips crossing the Potomac River in 1955. However, the model results were still 16 percent high even with use of the 8-min barrier.

TABLE 9

COMPARISON OF TOTAL TRIPS CROSSING POTOMAC AND ANACOSTIA RIVERS, FORECAST VS HOME INTERVIEW SURVEY, WASHINGTON, D. C., 1955

Forecast	Potomac River						Anacostia River					
	Orig. in Va. (×1,000)		Diff. ^a (%)	Orig. in Md. & D. C.		Diff. ^a (%)	Orig. South of River		Diff. ^a (%)	Orig. North of River		Diff. ^a (%)
	Survey	Model		Survey	Model		Survey	Model		Survey	Model	
1	123	153	+24.0	123	148	+20.2	144	163	+13.3	144	153	+6.3
2	123	149	+20.8	123	139	+12.6	144	163	+13.3	144	155	+8.1

^aComputed before rounding.

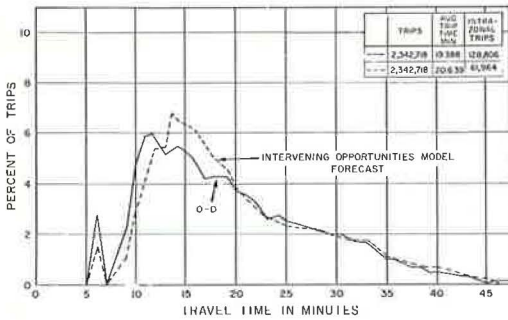


Figure 17. Comparison of trip length distribution (OD vs model), total trips, Washington, D. C., 1955.

The estimated zone-to-zone movements were again compressed and compared to actual movements (Table 8). By using the 8-min time barrier, the comparisons of these movements have been improved only slightly. Although the various tests indicate that a small improvement has been introduced by the incorporation of the additional 3-min barrier, the value of such adjustment lies in the reduction of bias in the important river crossing prediction. One additional test was made using a time penalty of 10 min to determine if the overestimate of 16 percent for trips crossing the Potomac River could be reduced. There was a very small improvement, reducing the overestimate to 14 percent. From selected skim trees, it was determined that the inclusion of the 10-min barrier had re-sorted the zones by time sequence so that almost all the zones located on the same side of the river as any given origin zone would be considered in the model before any zone on the opposite side of the river. In other words, the improvement made in the model in calculations of trips crossing the river through the use of a time penalty had reached a cutoff point. Any further increase in the quantity of the penalty would have very little effect in these calculations.

The various tests outlined indicate that the intervening opportunities model can be used to forecast travel patterns. When the different procedures used in the forecasts are compared, it is evident that both trip origin and destination adjustments are as necessary in the forecasting stage of this model as in the calibration stage. Likewise, if time barriers are required in the calibration stage, they should be estimated for the forecast year by analysis of the tolerable level of congestion over these facilities for the design year and use of the present relationship between barriers and level of congestion. This area still requires substantial research to insure a more accurate forecasting procedure. The forecasted L values could be improved if total person hours of travel could be forecast accurately. Research presently under way should improve this ability considerably (12, 13). However, with the adjustments made in L values for 1955 conditions, with the knowledge of total number of future trips only, travel patterns were estimated to a reasonably accurate level.

SUMMARY AND CONCLUSIONS

This research provides comprehensive evaluations of the intervening opportunities model as a procedure for simulating present and forecasting future urban travel patterns. Data from the Washington, D. C., 1948 home interview survey were used to calibrate the basic intervening opportunities model and test this model for its ability to simulate current travel patterns. The 1955 O-D survey data were used in the analysis of forecasts over the 7 year period made by this model.

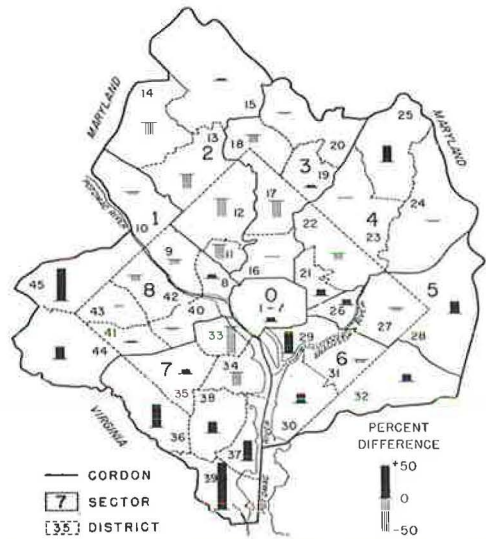


Figure 18. Comparison of total trips to zero sector, forecast 2, 8-min time barrier, Washington, D. C., 1955.

As part of this research, the original computer programming for this model was modified to make this theory of trip distribution available with input-output format which fits easily within other computer programs for transportation planning and analysis commonly in use throughout the country (14, 15). The basic program, with the exception of different input and output requirements, operates in the same manner as does the trip distribution portion of the total Chicago distribution and assignment package. The input and output of this program are discussed elsewhere. As research findings necessitated, two additional and optional features have been added to the basic program: (a) an adjustment which applies a uniform factor to all zonal origins to insure that all trips available are actually sent; and (b) an adjustment which operates in much the same manner, but at the opposite end of the trip. Zonal destinations are adjusted for an additional running of the program by examining the output of an initial pass of the program to insure that each zone receives approximately the correct number of trips.

In the calibration phase of this research, two methods of calibrating the model were tried. The first, using two different classifications of total trips, attempted to calibrate each purpose separately. The probability value (L) was adjusted until the average trip length for the estimated trips for that particular purpose was in close agreement with the actual average trip length for the same purpose. The two sets of trips for which these procedures were attempted were (a) home-based work, shop, school, social-recreation and other, and nonhome-based; and (b) long residential, long nonresidential, and short trips. The second classification of trips is that used in previous operational transportation studies utilizing the intervening opportunities model. Calibrating each purpose independently was not satisfactory for either set of trip categories tried.

The second method of calibration was accomplished using the long residential, long nonresidential, and short trip end categories but calibrating in a different manner. Each L value for a particular category of trips was adjusted based on the influence this category of trips plays on the total purpose trip distribution patterns, not to bring that category of trips into agreement with survey data.

A satisfactory duplication of 1948 travel patterns was obtained, using the second method of calibration, but with the following additional adjustments to the model. First, procedures had to be developed to insure that all trips were sent from each zone. Secondly, similar adjustments were found necessary to insure that each zone attracted approximately the correct number of trips. Of course, the need for such adjustments also exists with regard to other trip distribution models (5). Finally, a barrier to free travel in the form of a 5-min time barrier was necessary before the model would accurately distribute travel over the Potomac River.

The steps required to calibrate the intervening opportunities model should follow an orderly calibration procedure as just discussed. Sufficient testing of model results should be made to insure (a) that the correct number of trips are being sent; (b) that the average trip length and complete trip length frequency for total purpose trips are in close agreement with those from the O-D survey; (c) that trips received by each zone of the area are in close agreement to previously set zonal controls; and (d) that important movements such as river crossings or trips to large attractors, such as the CBD, do not reflect bias.

Such procedures were followed closely during the 1948 model calibration phase of this research, and the results clearly indicate that this model will provide an adequate duplication of travel patterns for the present period of time.

Several other observations should be made here. As stated earlier, the application of the intervening opportunities model reported here was the first to use a measure of terminal times in the analysis network. It is apparent that the overestimate of trips to the CBD would be even higher without the inclusion of the relative higher values of terminal times in the CBD.

The applications reported here used all person trips. In previous applications of this model, auto-driver equivalents have been used. There are apparently no unique problems in either approach and the decision on which to use depends primarily on considerations other than trip distribution, such as trip generation and modal split procedures.

There are also some questions raised when the model is examined closely regarding the extent of study area to be analyzed. The application reported here used only internal to internal trips. Other applications of this model have not only included the external surveyed trips but have also included some artificial measure of trip pull for population centers widely separated from the study area. By including the external trips, the need for adjustments to send all trips may be reduced or even eliminated. However, there is no indication that the use of internal trips only with the procedure to force all these trips to be sent introduced any bias in the estimated travel patterns.

Finally, the Chicago Area Transportation Study has recently developed procedures to apply a set of short L values in work being done by them in the Fox River Valley (16). These short L values are related to trip end density in the vicinity of the origin zone and the relationship used to forecast future short L values. The Upstate New York Transportation Studies have also been using a set of short L values and have applied them by ring instead of trip end density. Examination of the tests made in this paper indicate that the short category of trips are always the major problem. Both long residential and long nonresidential patterns are easily reproduced by the model. Future research and improvements in the applications of this model may well be in the area of a variable set of short L values.

Detailed tests of the forecasting ability of the intervening opportunities model were also made. From these tests several additional conclusions are evident. First of all, proper adjustments made to the present L values for the future year are critical in developing the model to the point where it can provide reliable future trip distribution patterns. The adjustments made in this research depended primarily on knowing only the total growth in trips. The use of the adjusted L values in this paper, based on this limited information, gave largely satisfactory results. However, the forecasting of L values would be strengthened enormously with additional knowledge of trends in trip length, either in time or distance, and with an increase in the ability to forecast more accurately the number of future intrazonal trips.

Finally, this research substantiated previous findings regarding the forecasting of time penalties required by physical barriers through the use of predicted tolerable congestion levels. The use of these penalty forecasting procedures did not completely eliminate error in river crossing prediction but did substantially improve them.

In conclusion, based on testing model forecasts over a 7-year period, the use of the intervening opportunities model to simulate and forecast urban travel will give satisfactory results if properly calibrated and tested. Even within the limited 7-year period, the total trips grew over 40 percent and several significant changes in the transportation system were made. The level of accuracy of the forecast year compares quite favorably with the levels of accuracy for the calibrated model measured against O-D survey data for the base year. Additional research into trip length trends and relationships should further strengthen the value of the intervening opportunities model.

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Discussion

ROBERT T. HOWE, Associate Professor of Civil Engineering, University of Cincinnati—The author is to be commended on his generally clear and detailed explanation of a rather complicated subject. This commentator must, however, raise several questions about the validity of the intervening opportunities model for predicting trip patterns.

In Eq. 1, L is defined as a "measure of probability that a random destination will satisfy the needs of a particular trip," and yet nowhere in the discussion is any apparent attempt made to make the summation of these L 's be unity, or certainty. This commentator cannot understand the manipulations of this equation when the author says:

"Next, with expansion of the right side of the equation,
$$\sum_{j=1}^n \left[e^{-LD} - e^{-L(D + D_j)} \right],$$

most of the terms cancel each other, leaving only $1 - e^{-L} \sum_{j=1}^n D_j$."

$$\begin{aligned}
 \sum_{j=1}^n \left[e^{-LD} e^{-L(D + D_j)} \right] &= \sum_{j=1}^n \left[e^{-LD} e^{-LD} \cdot e^{-LD_j} \right] \\
 &= \sum_{j=1}^n e^{-LD} \left[1 - e^{-LD_j} \right] \\
 &= e^{-LD} \left[1 - e^{-LD_1} - e^{-LD_2} - e^{-LD_3} \dots \right] \\
 &\neq e^{-LD} \left[1 - e^{-L(D_1 + D_2 + D_3 \dots)} \right] \quad (6)
 \end{aligned}$$

Early in Part E of the paper the author states that the model may not send enough trips out of a zone of origin or to a zone of destination, but when one uses a 5 percent or a 3 percent sample O-D survey as a source of information, he never really has correct information on such important statistics as how many workers really live in each zone or how many jobs are available in each zone. Would it not be well if an employment inventory were made at the same time that the dwelling unit inventory is made for the O-D survey?

Under his explanation of the method for determining preliminary values of "L," the author states "Also, it should be pointed out that in this case it was more desirable to work with the average trip length in minutes instead of miles. If miles were to be obtained, the output of the distribution program would require assignment. . . to obtain average trip length in miles." Presumably the time distances for calibration are obtained from the O-D data, but how does one arrive at future travel times, taking into account changes in the transportation system, if he has no idea of the actual trip lengths in miles? Earlier statements also seem to leave the measure of distance in some doubt: "Spatial separation for the intervening opportunities model is measured, not in absolute travel time, time, cost, or distance, but in the number of intervening destinations or opportunities," and "The probability factor L is empirically derived and describes the rate of trip decay with increasing trip destinations and increasing length of trip."

The terms long residential, long nonresidential, and short, as defined, seem to have little relationship to actual trip lengths; a 10-min shopping trip to the CBD would be "long," whereas a 20-min trip to a suburban center would be "short." The listing of L values given for each trip purpose indicates that the L factor for home-based shopping trips should be 19.22×10^{-6} without regard for length of trip, but Figure 5 shows L to be about 3.5 for "long residential trips" including, by definition, CBD-directed shopping trips, whereas Figure 7 shows L to be 5.60 and 9.75 for "short" trips including, by definition, all shopping trips not directed to the CBD. Table 2 indicates that the L value for home-based shopping trips was eventually increased to 67.13 through successive "adjustments." Later in the paper "short" is used to indicate intrazonal trips, but certainly not all non-work and non-CBD trips are really intrazonal.

Throughout the report emphasis seems to be placed on "adjusting" "L" values (a) to force the estimated mean travel time to equal the O-D observed mean travel time, and (b) to force corresponding travel time frequency distributions to match. It would seem to this commentator that more emphasis should be placed on reducing the over 30 percent RMS error indicated in Table 5 since the interzonal movements are the most important data.

Information given on forecasting 1955 travel patterns seems to cast further doubt on the process of selecting L values. Although it is stated that the Chicago method of developing projected L values was used as a guide, when the number of intrazonal trips in Washington was found to double between 1948 and 1955, the Chicago method was "modified." When the 1948 value of 5 min for river impedance did not produce

satisfactory predictions of 1955 travel, the river impedance was raised to 8 min, and when this still yielded a 16-percent error a 10-min value was tried. What would one do if he did not have the "future" data available to adjust against?

In the final paragraph of Section F the author states:

The various tests outlined indicate that the intervening opportunities model can be used to forecast travel patterns. When the different procedures used in the forecasts are compared, it is evident that both trip origin and destination adjustments are as necessary in the forecasting stage of this model as in the calibration stage. Likewise, if time barriers are required in the calibration stage, they should be estimated for the forecast year by analysis of the tolerable level of congestion over these facilities for the design year and use of the present relationship between barriers and level of congestion. This area still requires substantial research to insure a more accurate forecasting procedure. The forecasted L values could be improved if total person-hours of travel could be forecast accurately.

Since forecasting of any type involves dealing with many unknowns, it would seem to this commentator that any system of projecting trip patterns which requires accurate forecasts of total person hours of travel, in addition to the various essential land-use projections, plus estimates of future impedance, etc., can never be of great usefulness. What is really needed is a model which will simulate present and future travel patterns, without resort to the juggling of coefficients, exponents, etc., from city to city and from time to time. This commentator's electrostatic field model has given reasonable simulations of work trip desire lines in three cities (17, 18, 19) and of shopping trips in one (19), but no one has ever tested it as thoroughly as the author has now tested the intervening opportunities model. Since the latter has been found wanting, it is hoped that the field theory will soon be accorded an equally rigorous test.

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CLYDE E. PYERS, Closure—Professor Howe has allied himself with the entire field of urban transportation planners who look to the day when a model can be developed which will simulate present and future travel patterns without the need for adjustments from city to city and from time to time. If there is a possibility that such a model exists, it will surely be developed by those who have a good understanding of the strengths and weaknesses of the procedures in use today.

The purpose of the research reported in this paper is to improve the understanding of a widely used travel model, the intervening opportunities model, by giving a fairly detailed account of the application of this model over a period of time in a city showing significant growth. This would hopefully allow users to practice their art more efficiently and possibly would point the way to improvements in model technology. The fact that other models were also tested and comparisons were reported in a companion paper (6) made the results even more interesting.

Professor Howe has also raised certain questions in his discussion which should be answered. The first is related to the adjustment process which insures that all trip origins are actually sent. Apparently, the difficulty with the paper is related to the definition of D . The D being used has been defined as the destinations up to, but not including, zone j or, in effect, $\sum_{x=1}^{j-1} D_x$.

Treating this correctly, we have, from Eq. 1, for the zone first in time sequence from zone i :

$$T_{i1} = O_i \left[e^{-L D_0} - e^{-L (D_0 + D_1)} \right] \quad (7a)$$

for the zone second in time sequence from zone i :

$$T_{i2} = O_i \left[e^{-L (D_0 + D_1)} - e^{-L (D_0 + D_1 + D_2)} \right] \quad (7b)$$

for the zone third in time sequence from zone i :

$$T_{i3} = O_i \left[e^{-L (D_0 + D_1 + D_2)} - e^{-L (D_0 + D_1 + D_2 + D_3)} \right] \quad (7c)$$

and for the zone n th in time sequence from zone i :

$$T_{in} = O_i \left[e^{-L (D_0 + D_1 + \dots + D_{n-1})} - e^{-L (D_0 + D_1 + D_2 + \dots + D_n)} \right] \quad (7d)$$

With summation of both sides for all possible destination zones from 1 to n and with D_0 equal to zero, all but the first and last terms in the right side of the equation cancel out, yielding:

$$\sum_{j=1}^n T_{ij} = O_i \left[1 - e^{-L \sum_{j=1}^n D_j} \right] \quad (8a)$$

Dividing both sides by O_i yields:

$$\frac{\sum_{j=1}^n T_{ij}}{O_i} = 1 - e^{-L \sum_{j=1}^n D_j} \quad (8b)$$

Since the value of the right side of Eq. 8b is asymptotic and approaches a value of 1,

the term $\frac{\sum_{j=1}^n T_{ij}}{O_i}$ may be set at 0.98, or any other desired level, and an L can be

calculated which would send out this portion of the total trips.

As pointed out in the paper, an L value obtained in such a manner might not give a satisfactory trip length distribution. Thus, an L was sought which would give a satisfactory trip length distribution and each of the probability terms, i.e.,

$\left[e^{-LD} - e^{-L(D + D_j)} \right]$ was adjusted upward so that the summation of the probability terms would equal unity.

Professor Howe has questioned previously the adequacy of a 5- or 3-percent sample home interview survey to provide data on trips originating or designated to each zone (19). All transportation studies do check these data with other sources of information such as population, employment, and labor force by geographic location. Depending, of course, on such items as the definitions used, coverage, and methods of estimating, one source of information on labor force or employment may be better than others. But, of course, an information source designed to obtain data on employment and labor force by zone does not, by itself, provide answers on trips entering and leaving zones. The important point here is that certain adjustments were necessary to insure a balance between model inputs and outputs for both origins and destinations on a zonal level. This would have been true, regardless of the source of information for these input data.

In the research reported, time separation was used as a means of ranking destination zones from each origin zone. These times were derived from the transportation network. Future time separation is derived from the assumed future network, though in this case actual data were available and were used for the 1955 forecast network. The terms, long residential, long nonresidential, and short are clearly defined. As Professor Howe points out, any given short trip may be longer than one defined as long. Further examination of the actual data plotted on Figures 5 through 7 indicates definite patterns for the three categories of trips; it is seen that long trips have an average trip length some 40 percent greater than the short trips.

Information on several steps in the calibration process was included to provide as much insight on adjustments in L values as possible to future users of this procedure. Apparently, Professor Howe would use the application of a trial L value and subsequent model shortcomings as evidence that the theory is invalid.

A closer examination of the paper would have shown that Table 5, which Professor Howe cites, does not relate to interzonal movements at all. It is instead given to demonstrate the need for adjustments in the model so that each zone receives approximately the correct number of trips.

There are tables given statistically comparing interzonal movements, and examination of them indicates that each calibration step reduces the model error. Professor Howe seems to miss the entire point of model building when he criticizes adjustments to L to bring trip length into balance and suggests direct attempts to reduce the error in the interzonal movements. The intervening opportunities theory suggests that urban travel can be represented by a pair of decay rates acting on two different types of trips. If these decay rates (described by the L values) can be determined and applied to the appropriate trip ends, a matrix of zone-to-zone trip tables of acceptable accuracy can be calculated. This author feels that this was done in the subject research without any artificial zone-to-zone adjustment factors.

Again, the inclusion of several tests of forecasting ability with varying river barriers was done to provide some indication of the sensitivity and effect of the river crossing problem in the model. The 8-min barrier would have been used had this been an operational study, and the procedures used to estimate this value were fully referenced.

In any forecast of travel demand, a person-hours of travel check for reasonableness would seem elementary. It would also seem reasonable to adjust those forecasts to reproduce a sound estimate of person-hours of travel.