Improvements in transit services that provide more direct access to the terminals by reducing walking and waiting times and the number of connections can produce further modest gains for transit as an access mode. The difficulty is, of course, in providing a high level of service to the intercity terminals from all points in the terminals' catchment area.

Limousine services that provide express service between hotels and other central points in the CBD and specifically cater to passenger baggage requirements can attract a majority of passengers whose origins and destinations are in the CBD. These passengers can form a significant portion of the total trips in the catchment area.

Shared-ride taxis offer a compromise between the lower cost of public limousine and transit services and the convenience and speed of private automobile and taxi. They also provide service to nearly all parts of the catchment area of the Ottawa-Hull terminals. As a result, the evaluation estimates that shared-ride taxis can capture a substantial share of bus and rail passengers and a smaller share of air passengers. They offer a clear alternative to existing public transport services.

ACKNOWLEDGMENT

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Use of the Gravity Model for Pedestrian Travel Distribution

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Knowledge of pedestrian travel behavior is very important to attempts to improve congestion problems in central business districts. This paper describes the results of the use of a traditional gravity model for predicting pedestrian trip distribution. The model is calibrated by using a data set from downtown Chicago. The results indicate that the traditional gravity model closely reproduces the characteristics of pedestrian trip distribution and might be a useful tool in the analysis of downtown travel.

A great deal of discussion is now taking place on how to improve the central business districts (CBDs) of our major cities. Many proposals that are being evaluated and implemented deal with malls, personal rapid transit, downtown people movers, and sky walks. All of these systems have implications for the mobility of people in the CBD. Since much, if not most, of the CBD mobility is provided through pedestrian journeys, these proposals will certainly affect the number and length of such journeys and compete with them for patronage. An understanding of pedestrian trip distribution is, therefore, necessary in order to evaluate the potential impact of some new suggestions for the CBD.

The purpose of this paper is to review the calibration and application of a standard gravity model for a data set collected in Chicago in 1963 (1). This data set offers more than 10 000 origin-destination interviews in the Chicago CBD and presents the opportunity to test the gravity model on pedestrian travel behavior.

THE PEDESTRIAN SURVEY

The pedestrian survey was conducted by the Chicago Area Transportation Study (CATS). The interviews were conducted by people from various city departments in Chicago's downtown, known as the Loop, due to the elevated transit line that defines it. The survey was taken during the period from 7:00 a.m. to 7:00 p.m.; each interviewer collected a predetermined number of interviews. Interviews were collected randomly along 98 stations on one side of a street about three blocks in length for each hour in the time period.

The survey collected data for each station by hour, including purpose of trip, direction of travel, and whether the respondent was coming from work. The interviewer also obtained origin and destination addresses. The total number of people interviewed was 11 632. The sample rates for each station were based on pedestrian volume counts done by regular traffic counters the previous year.

The sampling techniques employed resulted in a sample that was uniformly distributed across the Loop area (i.e., an approximately equal number of interviews at each station). This distribution has two beneficial effects from a statistical standpoint.

1. It assures that blocks with low volumes on the edge of the Loop are not ignored (if a uniform sample were taken, very few trips from low-volume areas would be sampled, thus producing a possible bias), and

2. When the sample is expanded, the tendency will be to equalize the percentage of standard error of expansion across blocks (if a certain sample percentage were taken from a low-volume location and an equal percentage from a high-volume location and both expanded, the low-volume location expansion will have a larger percentage of standard error than will the high-volume location).

By surveying larger percentages in low-volume areas and smaller percentages in high-volume areas, the tendency will be toward an expansion that has smaller variance in the percentage of standard error than if a uniform sample were taken for the entire area. The problem of even getting a uniform sample, should one want it, would be nearly insurmountable in sidewalk interviews in a location such as Chicago's Loop.

This method of sample expansion and an analysis of the pedestrian travel characteristics were presented previously (2).

THE GRAVITY MODEL

The gravity model is calibrated by using the observed trip-length distribution to adjust model parameters. Analysis performed on the Chicago data (2) indicated that these data yield distributions of trip length that not only compare with other cities fairly well but could also, if necessary, be described with a simple negative exponential relationship. In short, it was apparent that the data to support the calibration of the gravity model were complete (i.e., trip-length distributions) and showed substantial promise.

The gravity model concept derives its name from Newton's law of gravity that states that the attraction between two bodies is directly proportional to their mass (or amount of attractions) and inversely proportional to some function of the distance between them. The form of the gravity model is as follows (3):

$$T_{ijp} = P_{ip} A_{jp} F(t)_{ijp} \Big/ \sum_j A_{jp} F(t)_{ijp} \qquad i, j = 1, 2, 3, \ldots, n \tag{1}$$

where

T_{ijp} = one-way trips from block i to block j for purpose p,
P_{ip} = trips produced at block i for purpose p,
A_{jp} = trips attracted to block j for purpose p, and
$F(t)_{ijp}$ = friction factor based on the travel distance between block i and block j for purpose p (ordinarily travel time would be used but since the level of service for walking is nearly constant, it is easier computationally to substitute distance, which is then directly proportional to time).

The premise of the gravity model is that trip interchanges can be estimated based on the relative attractiveness and impedance between the blocks in question. For this application, attractiveness is measured by the ratio of the number of trips attracted to block i for purpose p versus the total trips to all blocks for purpose p:

$$\text{Attractiveness of block j for purpose p} = A_{jp} \Big/ \sum_j A_{jp} \tag{2}$$

The impedance is calculated similarly in the following fashion:

$$\text{Impedance between block i and j for purpose p} = F(t)_{ijp} \Big/ \sum_j F(T)_{ijp} \tag{3}$$

Mathematically, $F(t)_{ijp}$ is a complex function but, in general, is proportional to a function of the inverse of the distance between blocks raised to a power, as is shown below:

$$F(t)_{ijp} \propto f_1 (T/d_{ij}^{f_2(n)}) \tag{4}$$

where d_{ij} = the distance between blocks i and j and $f_2(n)$ = a factor that depends on the trip purpose and trip length. Mathematical description of F(t) is quite complex, so it is generally described as a discrete distribution of numbers and not as a mathematical expression. The F(t) values are generally referred to as friction factors or impedances; however, as is indicated by the equation, the higher F(t) is, the more trips will be assigned to the i-j interchange. The F(t) values might better be referred to as travel propensities rather than frictions; however, to avoid confusion, this paper will continue to refer to F(t) as a friction factor or impedance.

In summary, the gravity model is based on very simple intuitive assumptions that deal with spatial separation of points and rewards or benefits available at these points. It has been applied widely in transportation planning and many examples of its use are available in the literature (4, 5).

Calibration of the Gravity Model

The calibration method adjusts the F(t) values iteratively until the trip-length distribution calculated by the model on the basis of distances between blocks is essentially equivalent to the observed trip-length distribution. The equivalence point is arbitrary and depends on the judgment of the person doing the calibration; however, a criterion of ±5 percent for the difference between observed and calculated mean trip length for each purpose has been suggested (6). This calibration technique is discussed further elsewhere (3, 4).

The computer formulation of the model first reads in the necessary inputs for the calibration phase; these are

1. The observed trip-length distribution for each purpose,
2. Initial estimated for F(t) values for each purpose (these can be based on prior knowledge of simply set equal to one),
3. Observed productions and attractions by purpose for all blocks in the area being studied, and
4. A matrix containing the distances between all blocks.

The model then distributes the trips based on the previously described equation for each purpose for as many iterations as the user specifies. During each iteration, trips are distributed over all blocks, new trip-length distributions are calculated, and new F(t) values are adjusted on the basis of the length distributions.

These F(t) values then serve as input to the next iteration. Once the calculated trip-length distribution is sufficiently close to the observed distribution, the model is then considered to be calibrated. Again, this point of calibration is determined by the planner based on judgment. The final calculated values of F(t) for each purpose are then ready to be used for the trip-distribution forecasting process. The calibration process is solely to obtain the F(t) or impedance function used in forecasting with the distribution model.

Calibration Results

To demonstrate how the model is stabilized (i.e., how the calculated trip distribution approaches that observed), Figure 1 shows the change in value of calculated trip-length distribution over five iterations. As one can see, the model rapidly approaches a stable point. This is somewhat dependent on the initial F(t) values assumed; should one use an initial value of 1.0, the process might take more iterations. This application began with a set of friction factors that have a slope similar to those found appropriate in other trip-distribution modeling efforts. The final, calibrated set of friction factors, however, was substantially different from the initial set.

The result of the full calibration can be analyzed by comparing the final trip-length distributions with the observed trip-length distributions. This comparison is best demonstrated in Figure 2, which shows the total observed distribution along with the calibrated distribution; this figure shows near perfect correlation. Another comparison is made in the table below, which gives observed and calculated mean trip lengths by purpose. Again, close agreement is apparent.

	Mean Trip Length	
Purpose	Observed	Calculated
To work	296	299
To home	335	311
To shop	274	274
Work-related business	299	300
Personal business	299	297
Social-recreation	247	244
All purposes	296	292

These curves are the result of the three initial iterations of one purpose to gain approximate values plus four additional iterations of each of the six purposes. It should be pointed out that the purposes that have

Figure 1. Percentage of trips by distance for five calibration iterations—"to work" trip purpose.

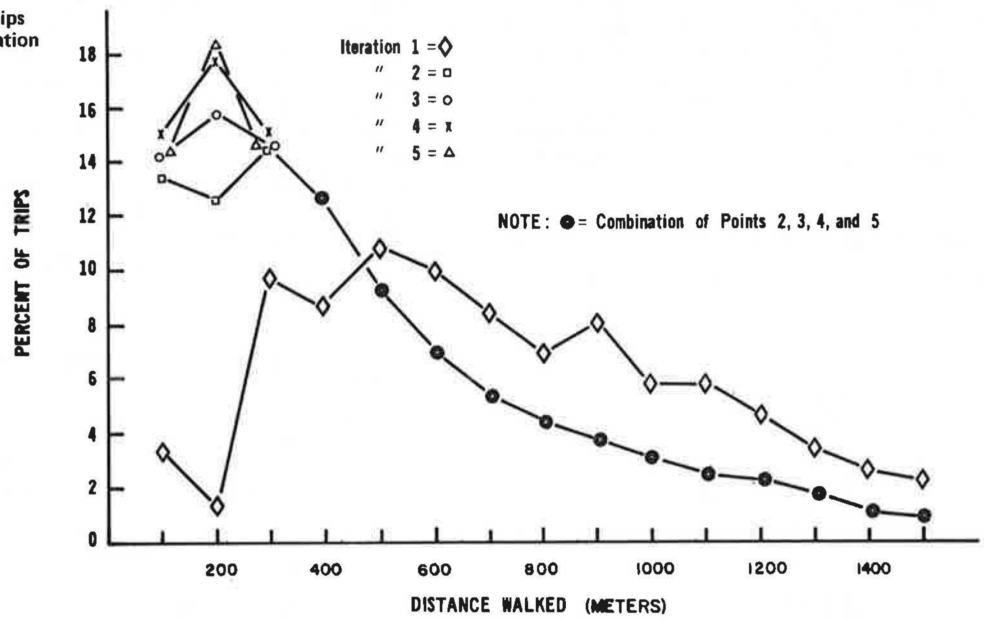
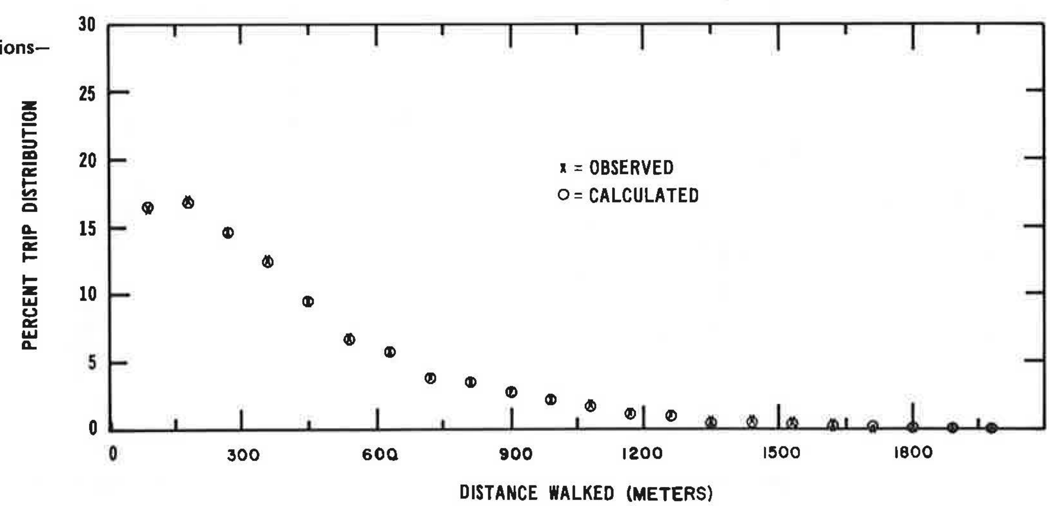


Figure 2. Observed and calibrated length distributions—all purposes and all trips.

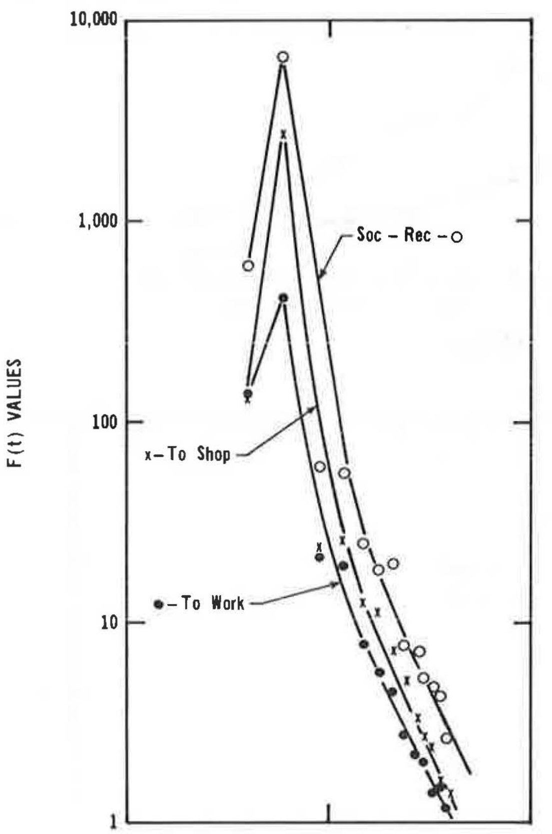


length distributions similar to "to work" (which were to home, work-related business, and personal-business) calibrated very rapidly, generally after one additional iteration over the initial three; it was necessary, however, to perform four additional iterations in order to establish stabilized F(t) values for purposes "to shop" and "social-recreation". It is evident from this experience that one can save a great deal of calibration time by starting with a realistic set of friction factors. Figure 3 shows the set of calibrated F(t) values for three representative trip purposes on a log-log scale. As expected, the shopping and social-recreation trips have more peak distributions, which indicates a propensity for shorter trips.

After the F(t) values have been calculated, one can plot and estimate a curve based on the points. From this curve, new F(t) estimates can be made that ensure that the values will decrease monotonically; this was not done in this study since the calibration values were essentially monotonically decreasing without further adjustment.

After the tables and curves are reviewed and, recalling that the basis for calibration was the observed trip-length distribution, one can conclude that the model has been successfully calibrated. A better test of the model is its ability to reproduce the observed trip interchanges between blocks. One check is available at this point, and that is to compare the friction factors calculated from the model with those found in a study done in Toronto (6). By using an average walking speed for downtown Chicago of 1.386 m/s (4.55 ft/s) so that the results here can be plotted on the Toronto study graph, the F(t) values for the "to home" trip (due to their association with transportation facilities) are plotted along with Toronto's values associated with terminals and appear in Figure 4. Keeping in mind that Chicago's "to home" values include trips to all modes, the Chicago values are generally within the curves that describe Toronto's envelope for trips to transportation facilities. This shows that the curves are generally similar and increases confidence in the calibration of the gravity model for Chicago.

Figure 3. Log-log plot F(t) versus distance.

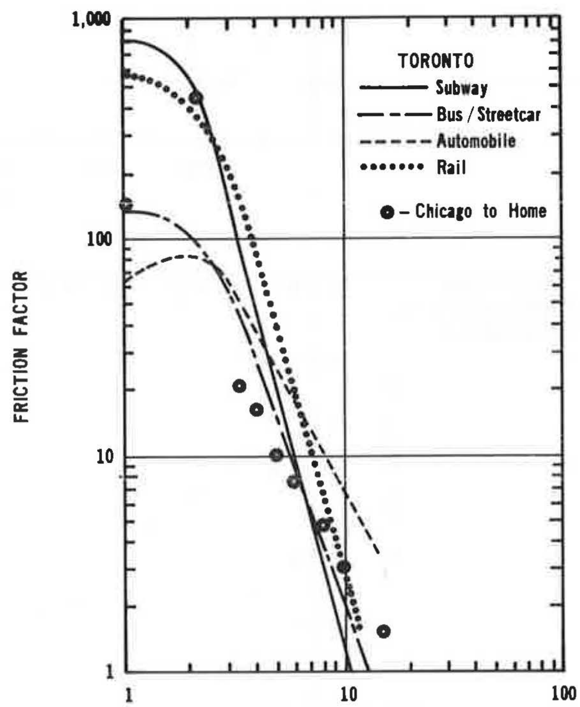


Possible Improvements to the Calibration Process

Numerous factors influence the trip-length distribution that was used as a basis for calibration of the gravity model. These factors include purpose of trip, time of day, employment status, and area of trip origin. It seems likely that the inclusion of these factors in the calibration process would result in a better description of travel. The inclusion of any of these items in the calibration process is quite easy; all one has to do is run the calibration separately for each factor in the same manner as was done for the six purposes. For example, one might decide to calibrate a separate model for various CBD areas, for employees and nonemployees, and for the six purposes. Should this be done, the model would undoubtedly be improved, but the cost of calibration would rise significantly and problems involved in forecasting these disaggregate values in the future would be difficult to surmount. The most reasonable adjustment to the model (for Chicago) would be to subdivide the trips by employee group and by two areas (Loop and fringe). This scheme, although it includes many factors found to affect trip length, would be less expensive to calibrate than the previous suggestion.

These extensions were not included with the current

Figure 4. Chicago F(t) values compared to those of the Toronto study.



Terminal walking time friction factors

research for several reasons: (a) it was felt that available resources could be better used in extending the applications of the model rather than fine tuning it for downtown Chicago; (b) once calibrated for the factors listed above, the model then used for the distribution process will again be more expensive since the distribution must be done for each trip group (a typical trip group might be trips by Loop employees for the purpose of work); and (c) it was felt the model was generally

Figure 5. Observed destinations—all purposes.

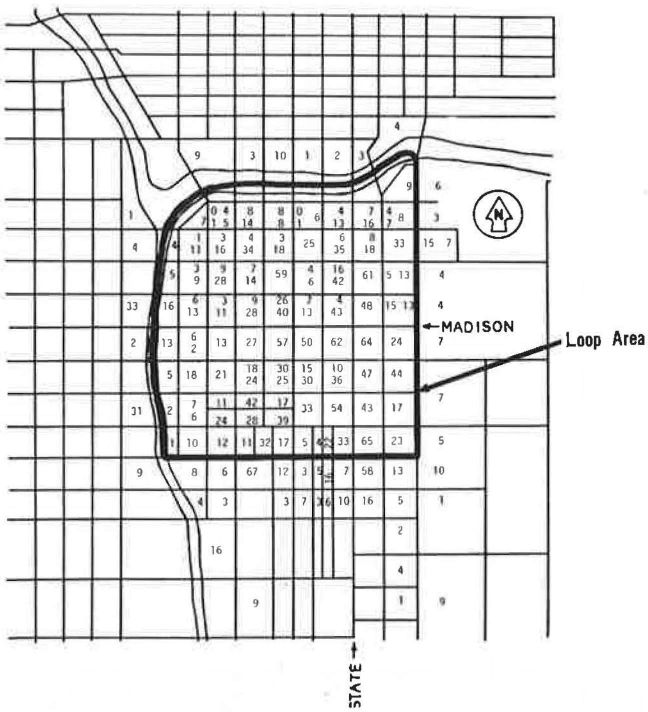
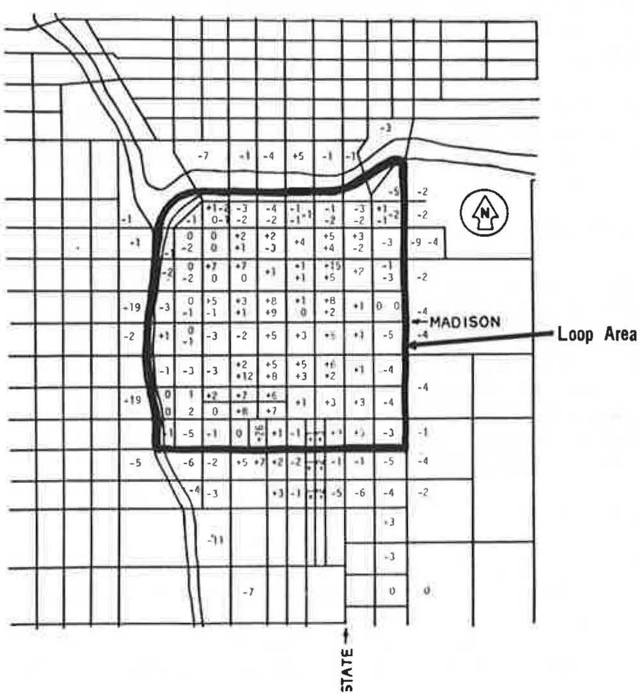


Figure 6. Model destinations minus observed destinations.



valid based on its overall calibration. Therefore, the model appears to be calibrated satisfactorily with respect to the observed length distributions, and the results compare favorably to another pedestrian study.

APPLICATION AND EVALUATION OF THE GRAVITY MODEL

In order to evaluate the performance of the gravity-distribution model, it is necessary to see whether or not it can reproduce the observed trip interchanges. The basis of evaluation for the calibration of the model was the reproduction of trip-length distributions; it did that nearly perfectly. The task at hand is to evaluate the model's ability to distribute trips to the blocks in the Loop in a similar manner as they were observed (i.e., Can this model send trips to blocks in the same numbers that were surveyed?).

The model results can best be presented by comparing the observed destinations per block with the destinations predicted by the gravity model (summed over all purposes). This comparison is made by observing Figure 5, which shows observed destinations, and Figure 6, which shows the difference between the calculated trip destinations and destinations observed. Agreement is fairly close; however, one can see that, in general, the model distributes too many trips to the central area and too few to the fringe. This indicates that the model cannot distribute trips adequately to the fringe areas. This is not a surprising result since the same set of F(t) values was used for fringe trips as for central trips. Further analysis showed that trips that originate in the fringe were much longer, since only external trips were surveyed and internal trips ignored, and would thus have different F(t) values. This can be seen in Figure 7, which shows the difference between length distribution for the Loop and fringe.

In particular, the commuter railroad stations located in the fringe did not get an adequate number of trips distributed to them. The observed destinations to the blocks west and south of the Loop with commuter stations totaled 70 000 trips, and the model only distributed a total of 21 000 trips. This may indicate that special generators, such as those on the periphery, must be treated differently.

The fringe area as a whole had a total of about 220 000 trips according to the observed data analysis, whereas the model distributed about 56 000 trips or only one-fourth of the observed total; the missing trips were distributed to the Loop area, which caused the totals there to be larger than observed. An adjustment of some sort is clearly needed and it seems clear that, as in models of vehicle trips, external trips must be modeled separately.

Another comparison can be made by relating the observed and distributed trips in Table 1. This table lists the distribution error by categories that represent the magnitude of trip attractions. One would expect more error for blocks that have large magnitudes and smaller errors for those with less (i.e., the percentage of error should be nearly constant over all the blocks). The results viewed from Table 1 are somewhat inconclusive since blocks in the 3000-9000 range had a larger percentage of error than other blocks. This probably reflects the poor distribution to the fringe blocks, which generally fell into this range. The error in blocks with larger values was quite small.

It seems that the gravity model produced a reasonable replication of the observed trip attractions, except for the fringe areas. It is important to note that these results were obtained without any special adjustments to the basic theoretical equation. In practical planning

Figure 7. Trip-length distributions for Loop and fringe—all purposes.

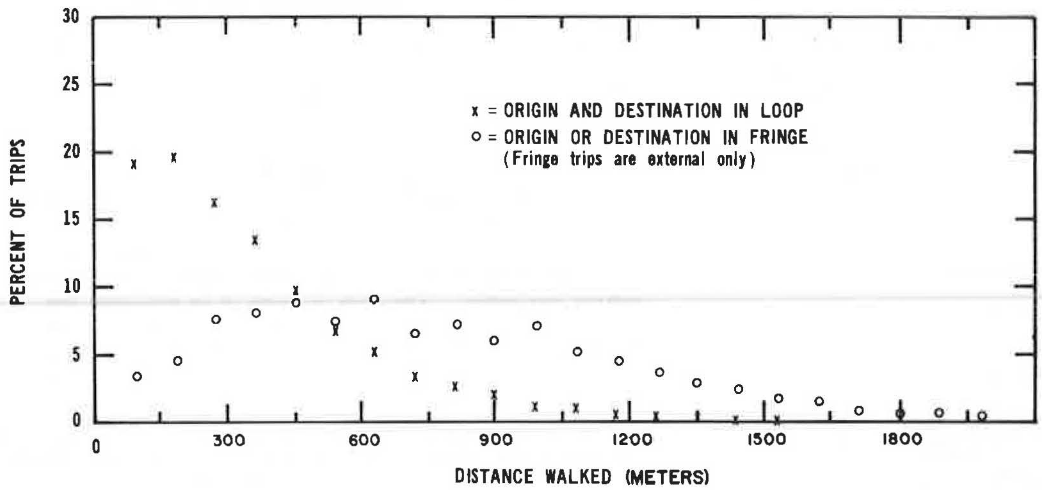


Table 1. Error for distribution by volume range.

Block Attraction	Error* ±1000	±1000-2000	±2000-5000	±5000-10 000	±10 000	Total
0-3 000	35	12	5			52
3 000-6 000	6	12	14	1		33
6 000-9 000	5	5	17	1		28
9 000-12 000	2	3	3	5		13
12 000-20 000	9	2	10	5	2	28
20 000-40 000	3	7	9	6	5	30
40 000	1	3	9	3	—	16
Total	61	44	67	21	7	200

*Error = observed-distributed trips.

efforts, such models usually go through a considerable amount of fine tuning (i.e., parameter adjustment) before reproducing observed results within reasonable limits.

Many applications of the gravity model for prediction of vehicular travel have used an iterative approach to ensure that the number of trips attracted to each zone is equal to the initially estimated trip attraction. The application of that approach in this research might have eliminated some of the problems discussed above. However, there is considerable uncertainty in the measured trip attractions and productions. Forcing the model to conform to the measured values of attractions, therefore, does not have strong appeal. (Productions, by definition, conform to the initial survey estimates.)

In a forecasting mode, some applications of the gravity model to vehicular travel prediction have foregone the step of balancing attractions on the grounds that, indeed, the gravity model is about as likely to give a good estimate of attractions as is the trip attraction model itself. This is a rather indirect way of letting accessibility assist in the determination of trip attractions: the gravity model attraction estimates are determined both by accessibility provided by the transport system and by the initial attraction estimated. Given the uncertainty in the input data and in spite of the lack of knowledge about accessibility-trip generation relationships, this latter approach was adopted for this research.

CONCLUSION

This paper has shown that pedestrian trip distributions are predicted fairly accurately by using a standard gravity model, and with a few simple modifications the accuracy can be greatly improved. This model outputs block-to-block interchanges that could be used as a basis to begin testing the impact of various CBD improvements, such as downtown people movers, which would compete with walking for patronage. A distribution model is central to any transportation-planning analysis. This study demonstrates that the gravity model (an institution in itself) can be easily adapted to pedestrian travel, and, therefore, provide an alternative framework for analyzing improvements to travel in CBDs.

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**G. S. Rutherford conducted the research on which this paper is based while at Northwestern University.*

Population Segmentation in Urban Recreation Choices

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The paper describes an investigation of various segmentation bases for capturing the behavioral differences in urban recreation demand. The analysis and evaluation of the segmentation bases were mainly achieved through the calibration of disaggregate quantal choice models (by using the multinomial logit technique) for each population segment and statistical comparison of these models and their estimated coefficients. After a preliminary elimination, three segmentation bases were selected for detailed evaluation: stage in the family life cycle, recreation-activity attractiveness, and geographic location. For each of the categories of these bases, a recreation-activity choice (a detailed trip-purpose) model was calibrated. These segment models were then compared with the pooled model both in terms of the overall goodness of fit and in terms of the differences in their coefficient estimates. Each of the segmentation schemes that was tried revealed significant differences and most of these differences bear plausible relation to the segmentation variables. Significant behavioral variations, which may result from differences in tastes, motivations, and personalities, may be captured through population segmentation.

Recreation is a broad and diverse area of human activity, encompassing a wide range of pursuits. Increased demand for participation in these activities creates, in varying degrees, increased use of transportation facilities. Visits to national parks alone have increased at an annual growth rate of about 7.5 percent in the period from 1957 through 1976 (1, 2). This is considerably higher than the population growth rate during the same period and also implies a very considerable growth rate in the consumption of fossil fuels for recreation activities.

The concern of the research in this paper is urban recreation and cultural activities. Most work on demand for recreation has concentrated on nonurban recreation and vacation activities (3-5), although many government units in urban areas are becoming increasingly concerned about issues of policy and investment in recreation facilities. If in the future transportation fuels are less available or the costs of such fuels are increased significantly, urban recreation facilities will probably receive the impacts of resulting changes in travel behavior. This will occur because travel to recreation is one type of travel most likely to be reduced or diverted from far sites to near ones (urban) in the event of high price or low availability of fuel. From a policy viewpoint, freedom to participate in a wide range of recreation activities may be considered to be one element of the high living standards enjoyed in the United States and Canada. Thus, substitution of local (urban) recreation activities for long-distance ones may be one way to prevent energy scarcity or high prices from eroding living standards.

This research introduces market segmentation as a means to understand and analyze recreation travel behavior. However, the paper deals only with recreation-activity choice (i.e., a detailed trip purpose) for a variety of reasons:

1. The reasons why people engage in recreation activities are much more complex, diverse, and numerous compared to other trip purposes. Recreation activities can be undertaken simply for fun or to fulfill various other complex psychological matters such as needs, motivations, and values. Hence, the consequences of recreation travel can only be understood after recreation behavior, per se, is understood. This is perhaps more crucial than for any other trip purpose.
2. Recreation is a gross trip purpose. The activities covered include a wide variety of activities and widely varying needs for travel, ranging from skiing to watching television. Thus, activity choice becomes an important issue, especially for the resulting travel implications.
3. We believe that the differences in individual tastes, motivations, and perceptions are the greatest influences on activity choice and, hence, concentrating on this choice can show the effects of segmentation more clearly.
4. The passage to recreational travel demand from recreation demand is a relatively trivial matter.

The basic demand-modeling hypotheses, which are described elsewhere (6), assume that both characteristics of the individual and attributes of the alternatives affect the choice process. Several mechanisms may be argued for the process by which these characteristics influence choices. One possibility is to use these characteristics as linear, additive terms in the utility function of the recreation activities. In this case, the effect of the characteristics is marginally to add to or subtract from the utility of activities and to affect the