An Analysis of Central Business District Pedestrian Circulation Patterns

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This paper examines the patterns of pedestrian circulation within the Toronto CBD for two pedestrian trip types. The first part of the paper develops a model of the pedestrian demands resulting from the location of the transportation system terminals and the configuration of office locations within Toronto. The model represents a standard application of the well-known gravity model formulation. The friction factors developed for the walking trips associated with each transportation mode are given.

The gravity model is also used to develop a simulation of the lunch hour pedestrian circulation patterns of the CBD office workers. However, a different approach is employed to calibrate the gravity model because the values of attraction were initially unknown. The iterative approach used is described in the paper. The friction factors used in the final calibration of the gravity model are given along with the generation and attraction rates for this type of CBD pedestrian trip. Finally, the paper presents information on the speed-volume-density characteristics of pedestrian flow.

•VERY little effort has been devoted to the analysis of patterns of pedestrain circulation within the central business districts of large urban areas. Although the amount of land consumed by pedestrian facilities in the CBD is insignificant when compared with the requirements of other transportation modes, the pedestrian circulation system is playing an increasingly important role in the articulation of CBD activities.

Morris (1), Benepe (2), and Stuart (3) have examined the role of the pedestrian in the CBD from the viewpoint of the city planner. All of these authors have noted the need for simple, quantitative models for predicting the pedestrian circulation patterns associated with CBD land-use plans. Morris (4) and Hill (5) have studied certain features of pedestrian circulation, but these studies were not sufficiently comprehensive to permit generalizations to be made for other urban areas.

The objective of this paper is to describe a study of pedestrian circulation in the Toronto CBD performed to develop predictive models for journey to work and lunch hour pedestrian circulation demands.

STUDY DESIGN

Information on pedestrian circulation characteristics was obtained by an office-based, questionnaire-type survey. Two distinct questionnaires were developed for distribution to selected office locations; one for the journey to work, and the other for the lunch hour circulation behavior of CBD office workers. Each type contained a series of questions and a street map of the CBD.

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There were 15,000 questionnaires distributed to 54 separate office buildings. Usable work trip questionnaires represented about 9 percent of the office work force, whereas the usable lunch hour circulation questionnaires represented about 5 percent of the work force.

JOURNEY TO WORK

The principal objective of this part of the study was to develop a model of the pedestrian demands resulting from the locations of the terminals of the metropolitan-wide transportation system and the configuration of office locations within the Toronto CBD. The model developed assumes a gross modal split and distributes trips from office locations to all the corridor transportation facility terminals within the CBD. The model developed represents a standard application of the well-known gravity model formulation.

The CBD street network and pedestrian ways were coded into a network consisting of 458 centroids arranged essentially in a grid configuration. Office zones were made up of facing pairs of block-faces with the centroid located at the midblock. The office zones were linked from block-face to block-face, and from block-faces to transportation centroids.

The inputs to the gravity model were the generation and attraction rates of office and transportation zones, a family of friction factors, and a set of minimum-path walking trees from all office centroids to all transportation zones. Office generation rates for each mode were based on employment figures for each office zone and the existing modal split proportions. Attraction rates for the transportation terminals were based on observed exit volumes associated with each transportation terminal. The attraction of a transportation terminal of a mode was assumed to be proportional to the fraction of all mode users exiting from that terminal, and to the total office employment. For example, the attraction of a subway zone was calculated from

$$A_j = \left(\frac{SV_j}{\sum_j SV_j}\right) \times 0.486 \text{ (total office employment)}$$

where

SV_j = subway volume observed exiting at j, and

j = number of subway stations.

The constant 0.486 is the existing proportion of CBD office workers traveling by subway.

A comparison of the trip length distribution curves from the final calibration of the gravity model with the actual trip length distributions indicated generally good agreement between the two for the walking trips associated with the four corridor transportation modes. Figure 1 shows the friction factors used in the final calibration of the gravity model, as well as the exponents of the linear portions of the curves.

Trips were assigned to the network using an all-or-nothing procedure and compared with the survey ground-count volumes. Generally good agreement was obtained between the assigned and observed volumes. A completely objective comparison was not possible as the ground counts included pedestrians involved in walking trips other than completing the journey to work.

LUNCH HOUR CIRCULATION PATTERNS

The gravity model was also used to develop a simulation of the lunch hour pedestrian circulation patterns of the CBD office workers. However, it was necessary to alter the usual approach to calibrating the gravity model because the values of attraction (A_j's) were unknown initially. Assuming that the gravity model is an accurate representation of the way in which people actually choose the destination of a trip, all trips in any survey sample will have already been through a real life gravity type distribution. The number of trips in a sample attracted to any destination is not a value of the attraction but the value of attraction discounted by the separation of the destination from the origin where the sample was taken.

The gravity model formulation may be expressed in the following alternate manner:

$$A_j = \frac{A_j^*}{\left(\frac{\sum_{i=1}^{n} P_i \cdot F_{ij}}{\sum_{j=1}^{n} A_j \cdot F_{ij}}\right)}$$

where

A_j = unknown attraction of zone j,

A_j^* = known attraction force from the survey,

P_i = known trip production of zone i from survey, and

F_{ij} = friction factor for distance i - j.

This equation in A_j may be solved by an iterative process. A value of A_j may be estimated and inserted in the right-hand side of the equation and a new value of A_j generated, and the process continued until the A_j's are identical. The friction factors are also unknown and the iterative process must also generate these. It is possible to iterate the model successfully on two unknowns because the model is very much more sensitive to a change in F_{ij} than to a change in A_j and therefore tends to converge to a stable solution fairly rapidly.

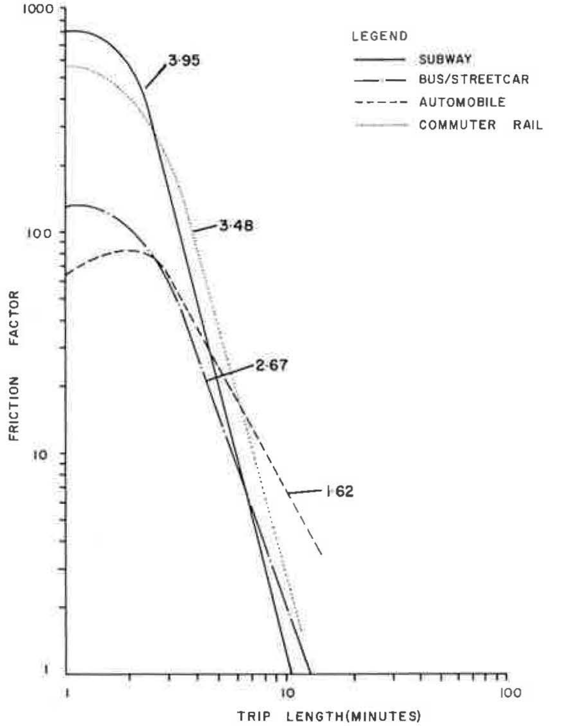

Figure 1. Terminal walking time friction factors.

The magnitudes of A_j were obtained by iterating several runs of the gravity model on the survey data. Then these A_j values were used with areawide employment and land-use data to obtain a full-scale simulation of pedestrian movements. The gravity model was calibrated to the survey data for three trip stages; (a) office to shop, (b) shop to shop, and (c) shop to office. Trip productions and attractions and trip length frequency distributions for each stage were tabulated from the survey data for use as inputs to the calibration.

The minimum-path measure of separation used in the calibration incorporated walking time, waiting time at street intersections, street attractiveness, and a turn penalty. This was necessary because it was found that minimum time paths were not followed by pedestrians for this trip type. The particular measure used was developed from the walking paths indicated on a random sample of the questionnaires and had the form

$$d_{ij} = T + 0.5W + 0.4(T - A) + T_u$$

where

d_{ij} = measure of separation used in gravity model,

T = walking time (minutes),

W = waiting time (minutes),

A = attractiveness factor (F) times walking time in minutes,

F = length of attractive features on both sides of a link divided by twice the length of a link, and

T_u = turn penalty of 0.01 minutes for each turn made.

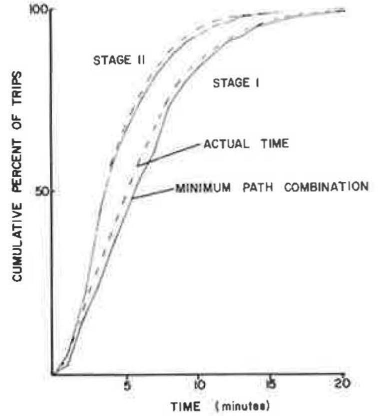

Figure 2. Walking time distributions for actual and minimum path measure.

Figure 2 shows the walking time frequency distributions for actual walking times and for the minimum-path measure of separation for the first and second stages of the lunch hour trip. The third stage distribution was identical with the first stage distribution. Table 1 provides a comparison of the actual time distributions and the minimum path distributions.

The questionnaire survey revealed that employees leaving their offices at lunch hour made an average of 1.7 visits to shops, restaurants, etc. Table 2 shows a breakdown of these rates by purpose of shopping. No direct measurements of attraction were made because of the difficulties of obtaining a large enough sample of door counts.

Table 3 provides estimates of the gross trip attraction rates for the first three trip purposes of Table 2. These rates were determined by aggregating land-use and employment data and trip-end information from the survey. The employment information for the department stores is inflated because it includes workers in mail order sections and offices as well as sales clerks. The employment figure for retail shops is low because the available land-use information does not include all stores with employment of less than 10 persons.

Attraction rates for personal business trips to banks, trust companies, and the City Hall could not be estimated because the land-use data available included all workers at these locations, the majority of whom were not employed in customer service. It has been pointed out that since it was not possible to define completely the attractions in terms of land use and employment, the gravity model was calibrated to the survey data and the calibrated model was then used for the full-scale simulation.

A minimum path assignment was included in the final iteration of the gravity model calibrated on the survey data, and the assigned volume on each link matched the minimum path assignment to a high degree as indicated by the following correlation: Gravity model volume = 0.97 + 1.036 × minimum path assignment volume, $R^2 = 0.987$. The number of trips attracted to each zone in the model was identical with the number of trips in the sample.

The output of the final run of the gravity model calibrated to the survey data was (a) a set of values of the attraction of each zone for each stage of the trip, (b) a set of friction factors for each stage, and (c) a value of accessibility of each zone for each stage. The accessibility measure is the denominator of the gravity model and is a measure of the relative strength of all the attractors surrounding a zone of trip generation.

Figure 3 shows the proportion of employees leaving a building as a function of the first stage accessibility and it illustrates the nonlinear nature of this relationship.

TABLE 1

COMPARISON OF TRIP TIME DISTRIBUTIONS

Stage		Mean Trip Length	Median Trip Length
Stage 1 (office to shop)	Actual	6.0	5.2
	Minimum path	6.4	5.6
Stage 2 (shop to shop)	Actual	4.4	3.5
	Minimum path	4.5	3.5
Stage 3 (shop to office)	Actual	6.9	6.3
	Minimum path	7.0	6.6
Total trip	Actual	15.9	15.0
	Minimum path	16.5	15.5

TABLE 2

TRIP PURPOSE BREAKDOWN

Activity	Visits Per Head
Department store	0.57
Retail shop	0.36
Restaurant	0.36
Personal business	0.29
Recreational stop	0.06
Recreational walk	0.05
Transportation	0.01
Total	1.70

TABLE 3

TRIP ATTRACTION RATES

Trip Goal	Trips Attracted	Gross Floor Area	Employment	Trips Attracted (per 1000 sq ft)	Trips Attracted (per employee)
Department store	39,000	2,173,000	16,500	13.3	1.8
Retail shop	18,000	1,273,000	3,650	14.1	4.9
Restaurant	18,500	1,522,000		12.1	

Although the accessibility measure is an arbitrary value, the saturation value at which maximum generation is reached may change from place to place, but the shape of the curve will remain the same.

The implications of Figure 3 are more clearly understood by drawing isopleths representing the generating intensity of each part of the CBD. Figure 4 shows the contours of this primary generation rate for the CBD area. Figure 4 also shows that the area of maximum generation is centered around the major department stores with an extension north and south along Yonge Street which has the principal concentration of retail trade establishments.

An attempt was made to relate the value of the attraction (A_j) generated by the gravity model for each trip purpose to the land-use and employment characteristics of each zone by multiple regression analysis. This analysis failed to produce a meaningful result for the majority of zones with a low value of attraction because the standard error of estimate was of the same order of magnitude as the value of attraction. The principal reason for this failure is that the land-use and employment data available were not sufficiently accurate, particularly for those zones containing a large number of small establishments and mixed land uses.

Figure 5 shows the friction factors developed for each stage of the lunch hour trip with the exponents of the linear portion of each curve. The tangent gradients on the first and third stages of the trip are virtually identical showing that these trip stages may be interchanged, the outward distribution being the same as the inward distribution. The friction factors for the intermediate stage have a flatter tangent which shows that people are more indifferent to walking between shops than leaving the office. However, the curve steepens considerably after the 12-min interval showing that they will not walk much further than this distance between shops.

The final test of the simulation model was a full-scale run using the total office employment in the study area as an input. Using the primary generation rate curve of Figure 3 and the total office employment, the number of people making trips from each zone was determined. The trip attraction of each zone was the value of A_j determined from the final run of the survey gravity model, and the friction factors used were those for this run. A simple gravity model distribution yielded the number of trips to each

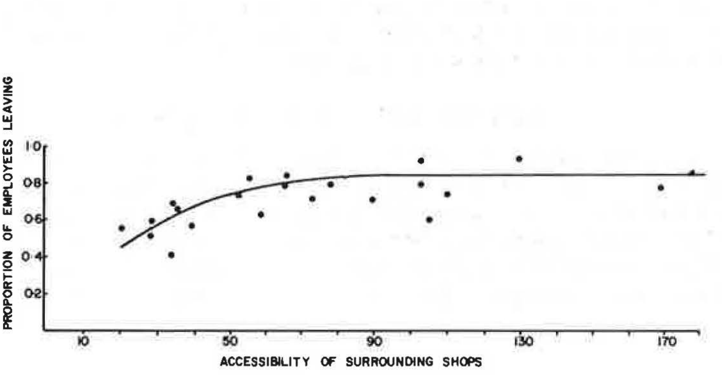

Figure 3. Primary generation rate from office buildings.

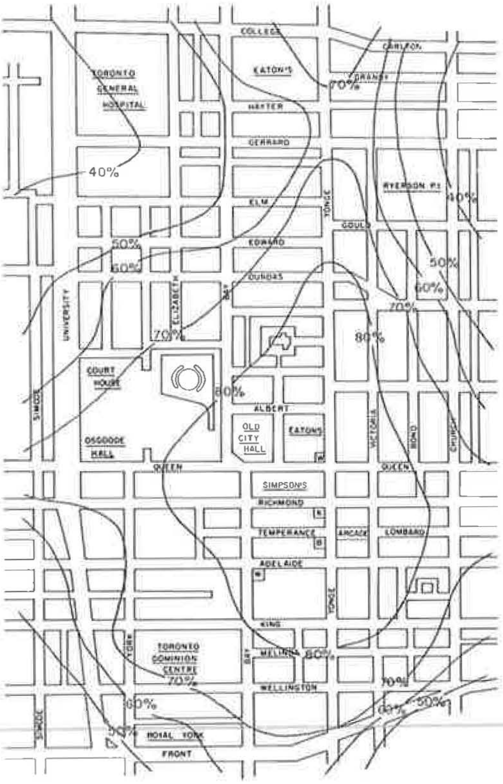

Figure 4. Primary generation rate contours.

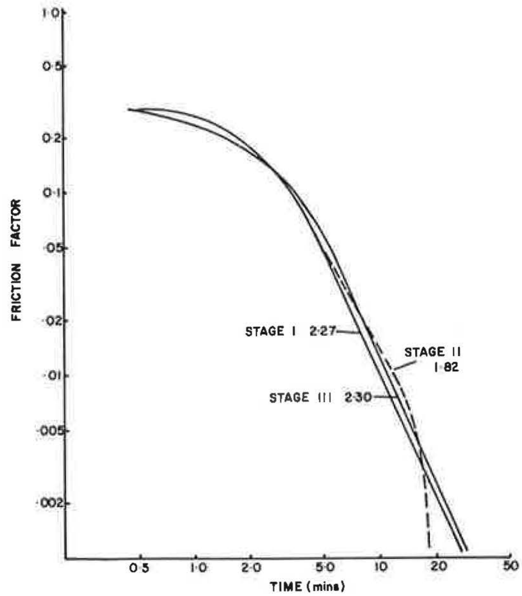

Figure 5. Friction factors for lunch-hour trips.

zone and an assignment of the trips to each zone.

A second distribution between shops was made by taking the first stage arrivals at each zone and applying the uniform secondary generation rate (0.7) to give the second stage generation. This was then used as the input for a second stage gravity distribution, that yielded another assignment and number of trips attracted. Because the survey had shown that the final stage was similar to the initial stage, no further distribution was made and the final link volumes were obtained by doubling the first stage volumes and by adding the second stage volumes. There was good agreement between the assigned volumes and the control counts suggesting that the calibrated gravity model was a reasonable approximation of the lunch hour circulation patterns of office workers.

North of Queen Street, the assigned volumes were lower than the control counts and much of the discrepancy could be explained by the nature of the land uses. There are large institutions such as Ryerson Polytechnic and the hospital complex on University Avenue that are generators of lunch hour trips although they are not offices and are therefore not included in the full-scale simulation.

SPEED-DENSITY FLOW RELATIONS

Figure 6 shows the relationships between walking speed and pedestrian density that have been established for various types of pedestrian components. Figure 7 is derived from Figure 6 and shows the relationship between speed and flow for the several types of facility. This relationship shows that the maximum capacity of all facilities is about the same. There are 1400 to 1500 persons per ft width per hour at approximately 2 to 2.5 ft per sec with a maximum density of approximately 0.2 persons per sq ft.

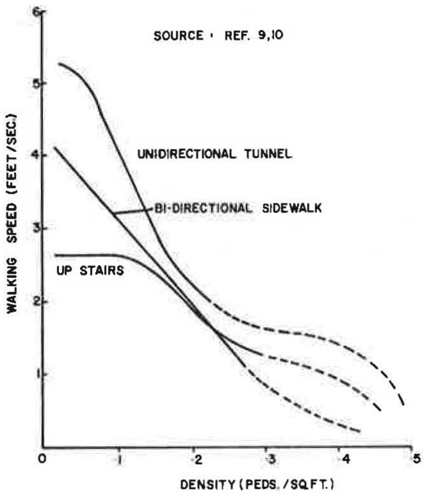

Figure 6. Pedestrian speed-density relations.

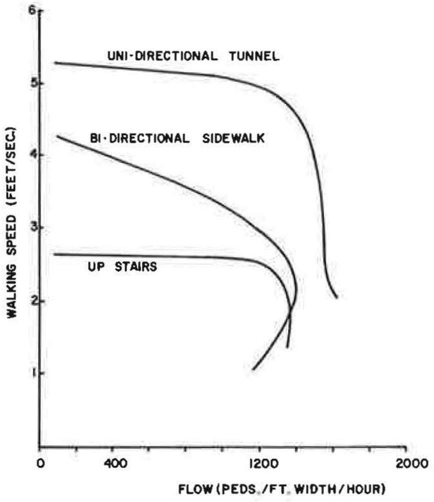

Figure 7. Pedestrian speed-flow relations.

SUMMARY

The central business districts of many medium and large urban areas are being modified to provide for the separation of pedestrian and vehicular traffic in order to improve pedestrian environment and to increase the efficiency of vehicular circulation. In addition, a number of urban centers are examining the feasibility of improving intra-CBD circulation of persons through the installation of mechanized transportation devices.

The investigation described in this paper demonstrates the validity of using a gravity model to simulate the patterns of pedestrian movement for two types of trips. Models such as these provide an objective basis for evaluating the usefulness of any proposals for improving pedestrian circulation within the CBD.

It is well known that the functions of many CBD's are becoming specialized and that the principal function in the future will be the office function. In addition, the other major CBD activity, retail trade, is becoming increasingly dependent on the CBD office work force for sales. The model developed for the lunch hour trip patterns of office workers provides a basis for examining the impact of various CBD land development proposals on pedestrian volumes, and consequently their probable impact on existing or proposed retail trade areas.

The generation rate-accessibility relation of Figure 3 and the friction factors shown in Figures 1 and 5 provide important information that could be employed in the CBD's of cities with a structure similar to that of Toronto. In other areas it would be a simple matter to conduct an office-based survey of the type described in this paper to generate data to calibrate a suitable model.

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