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Number 355

Pedestrians

6 Reports

Subject Areas

52	Road User Characteristics
53	Traffic Control and Operations
55	Traffic Measurements

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FOREWORD

Although pedestrians are sometimes referred to as the "other highway users", they are receiving a sizable share of research attention. The six papers in this RECORD are principally concerned with the capacity of facilities to accommodate pedestrian movements. In addition, they contain interesting information about study techniques and pedestrian-handling concepts. Engineers, architects, and administrators responsible for pedestrian movements will find these reports informative and readily useful.

Readers familiar with the Highway Capacity Manual will quickly recognize the parallel "level-of-service" concept developed by Fruin. Using time-lapse photography, six levels of service are established that can be used in the design of new facilities or in the evaluation of old ones.

Conflicting demands by two different groups of 2 sidewalk users—normal business and tourist flow versus three kinds of orderly demonstrator flows—were evaluated for the sidewalk in front of the White House. This work by Surti and Burke may have wider applicability in pedestrian control than would appear at first glance.

Nesselrodt and Yu sought to identify relevant variables in the pedestrian effect on vehicle flow at at-grade intersections. From a candidate list of 24 variables, nine judged to be most significant were selected for the final analysis. Using the models they developed, the authors suggest that it should be possible to predict intersectional vehicular delays due to pedestrian effects.

Concern for overlooked factors in the design of CBD pedestrian facilities led Pushkarev and Zupan to study relationships among pedestrian densities, walkway space, and building floor space and use. Their findings include suggested relationships between daily trip generation rates and the relative magnitude of design period flow that should be useful to designers.

Pedestrian circulation systems in Canada are discussed in a paper by Pendakur. Systems that coordinate, as well as those that segregate, vehicles and pedestrians are discussed. A number of conclusions are reached relating to public and private financing, transit links, and design trends.

In the final paper, Levinson describes case studies of pedestrian circulation in the southwest section of Washington, D.C., and in the downtown area of Seattle, Washington. He concludes with observations about the demonstrated importance of achieving pedestrian movement continuity, separating pedestrian and vehicular movements, and preserving (or reserving) pedestrian corridors.

CONTENTS

DESIGNING FOR PEDESTRIANS: A LEVEL-OF-SERVICE CONCEPT

John J. Fruin, The Port of New York Authority

Pedestrian facilities should be designed on the basis of qualitative as well as quantitative factors. Present procedures involve the use of maximum capacity ratings for design. The capacity of a pedestrian traffic stream invariably occurs at the heaviest concentrations combined with restricted walking speeds. This condition is not representative of a comfortable human environment. Time-lapse photography studies make it possible to establish the relationship between volume, speed, and human convenience at different pedestrian concentrations. The studies form the basis for six levels of service for the design of walkways and stairways. These levels of service provide a qualitative method of designing new or evaluating existing pedestrian environments.

•THE design of pedestrian facilities involves the application of traffic engineering principles combined with consideration of human convenience and the design environment. Different environments logically require the application of different qualitative as well as quantitative design standards. The design rationale for shopping areas would not apply to transportation terminals, and it follows that airport terminal standards would not apply directly to rapid transit facilities. Each area has its own traffic patterns, physical restraints, and individual environmental requirements.

The Traffic Engineering Handbook (1), the most authoritative reference on pedestrian design, provides a series of capacity ratings for walkways and stairways based on cordon counts made at several locations. In each case the capacity of the section under heavy pedestrian flow is reported; however, there is no evaluation of human convenience associated with these capacity ratings. Traffic engineers recognize the principle that maximum capacity of a traffic stream occurs in the region of maximum density. When this principle is related to pedestrian flow, it can be seen that maximum capacity volumes are attained only when there is a dense crowding of pedestrians. Crowding significantly reduces pedestrian convenience because normal walking speeds are restricted and the freedom to maneuver in the traffic stream is limited. Because human convenience is one of the primary considerations in environmental design, design standards for pedestrians must be based on a relative scale to provide the desired design environment.

LEVEL OF SERVICE FOR PEDESTRIANS

The level-of-service concept for highway design contained in the Highway Capacity Manual (2) offers a model approach to the design of pedestrian ways as well. The manual describes six levels of design ranging from A to F based on service volumes, volume/capacity ratio, and a qualitative evaluation of driver convenience. Included in this evaluation is the individual freedom to choose desired vehicle operating speed, the ability to overtake and pass other vehicles, and the freedom to change lanes.

Pedestrian level-of-service standards similarly should be based on the freedom to select desired walking speed, the ability to bypass slower moving pedestrians, the ease

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Sponsored by Committee on Pedestrians and presented at the 50th Annual Meeting.

of crossing, and the presence of reverse flows at various traffic concentrations. These standards would provide a basis for qualitative as well as quantitative design. The data required to define relative levels of convenience of pedestrians have been difficult to collect with normal field survey procedures; therefore few observations of this type have been made. However, time-lapse photography techniques make possible the collection of large amounts of data that can subsequently be analyzed in great detail. These data provide the means for a more definitive evaluation of traffic flow relationships and human convenience.

THEORETICAL BASIS OF STUDY

The development of pedestrian traffic flow relationships from time-lapse photography analysis is based on the classic equation of traffic flow (derived from the original analogy to fluid flow). This equation is usually expressed in the form

$$q = uk \tag{1}$$

where

q = mean flow rate,
u = mean speed, and
k = mean concentration or density.

This equation has been used to describe pedestrian flow, but the use of mean concentration or density, k, results in expressing pedestrian concentrations in tenths of a pedestrian per square foot, an unwieldy and somewhat unnatural unit to work with (3, 4). The use of the reciprocal of density, or square feet area per pedestrian—the pedestrian module, as used in this paper—allows a much clearer visualization of the pedestrian environment and relative quality of service. To describe pedestrian traffic flow in terms of the pedestrian area module, with changes in notation adopted for this study, Eq. 1 is rewritten as

$$P = \frac{S}{M} \tag{2}$$

where

P = mean flow rate, pedestrians per foot width per minute;
S = horizontal space mean speed, feet per minute; and
M = pedestrian area module, square feet per pedestrian.

The horizontal measurement of speed (and area) is required to maintain the consistency of the equation and to provide area modules for stairways based on horizontal tread occupancy. All time-lapse photography studies of pedestrian flows were based on the measurements of the volume, P—i. e., the number of pedestrians crossing the centerline of the field of measurement during the photographic sequence—and the pedestrian module, M—i. e., the average pedestrian occupancy of the field during the sequence. The space mean speed, S, was derived from these measurements by use of Eq. 2. This method is one of several suggested by Edie for measurement of traffic flow by sampling processes such as time-lapse photography (5).

PEDESTRIAN TRAFFIC FLOW ON WALKWAYS

Three time-lapse photography studies, with minor modifications in techniques due to progressive experience and analysis of the initial data output, were conducted of walkway flows. The first experiment consisted of photographing directionalized flow through a 10-ft wide channel erected parallel to the main stream of peak-hour pedestrian traffic at a large commuter bus terminal. The channel was progressively narrowed in the subsequent two experiments in an attempt to produce higher density flows. In the last experiment of the series, a funnel-like approach was erected at the entrance to a 6-ft wide channel to further concentrate traffic. The data takeoff of volume, P, and

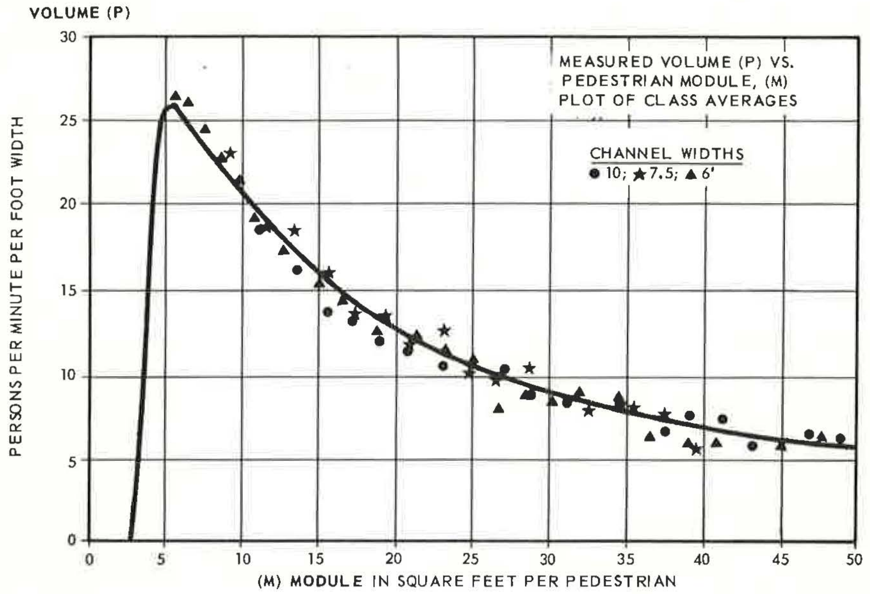

Figure 1. Pedestrian volume versus space for unidirectional traffic flow on walkways.

average pedestrian area occupancy, M, were organized in class averages. The data were then fitted mathematically by the method of least squares (6).

Figures 1 and 2 show the results of photographic studies of unidirectional flow including the mathematical curve of best fit. The equation for the curve of best fit based

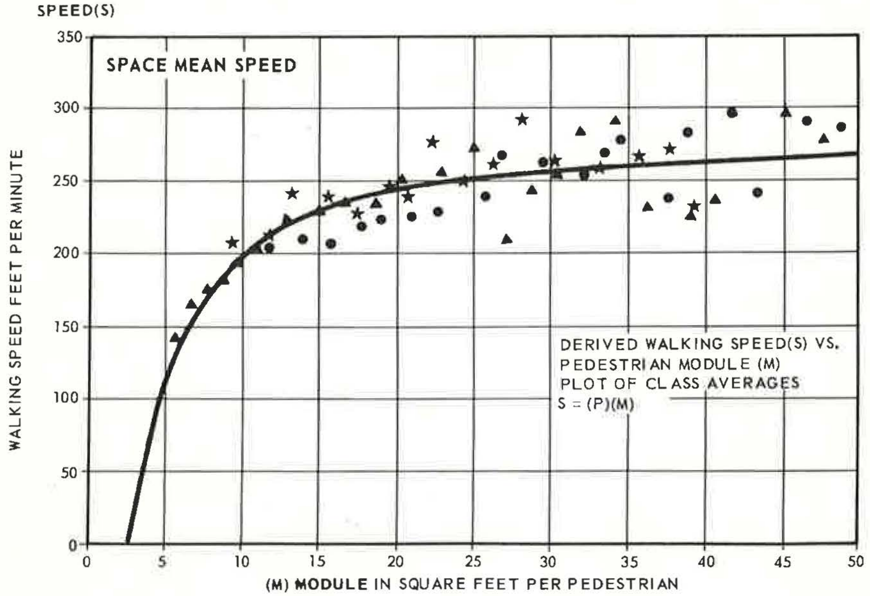

Figure 2. Pedestrian speed versus space for unidirectional traffic flow on walkways.

on a least-squares fitting of the flow data is, for unidirectional flow,

$$P = \frac{281M - 752}{M^2} \tag{3}$$

A least-squares fitting of data from a single study of flow for a 6-ft wide channel yielded the equation for bidirectional flow,

$$P = \frac{267M - 722}{M^2} \tag{4}$$

The plot of volume versus pedestrian area occupancy in Figure 1 shows that maximum volume is attained at an average pedestrian area occupancy of approximately 5 sq ft per person. Volume drops sharply until an average area occupancy of 25 sq ft per person, beyond which the effect of pedestrian area occupancy on volume is moderated. Similarly, the companion walking-speed and area-occupancy curve (Fig. 2) shows that pedestrian walking speeds fall below the normal mean of about 250 ft per min at 25 sq ft. At 5 sq ft the speeds are below the range established as the limit of normal walking-speed surveys, which indicates that pedestrians are forced into a restricted "shuffling" gait at this point. These breakpoints provide a useful measure for delineating levels of service and convenience.

Maximum flow volumes of 26.2 and 24.7 pedestrians per minute per foot of walkway developed by the time-lapse photography study compare with a value of 27 recommended by Hankin and Wright for capacity design in London subways and design values of 28 and 25 reported by the Chicago and New York Transit Authorities respectively (7, 8).

Because all of these capacity values occur at or near the critical region of pedestrian area occupancy, their use for design actually results in a very poor standard of pedestrian traffic flow, with a dense crowding of pedestrians, shuffling walking speeds, intermittent stop-and-go movement, and pedestrian conflicts.

Crossing Conflict Study

To provide supplementary information for the determination of level-of-service standards, a study was conducted of the occurrence of pedestrian conflicts when crossing mainstream traffic. A time-lapse camera was set up above a location where pedestrians occasionally cross a traffic stream at right angles. A total of 61 crossing movements at various levels of traffic density were observed, and the number of conflicts were recorded. For this study, a conflict was defined as any stopping or breaking of the normal walking pace due to close confrontation with another pedestrian. These confrontations required pedestrians to adjust their speed and/or direction to avoid collisions. The probability of pedestrian conflicts is obviously a function of pedestrian spacing and speed. Although larger pedestrian spacings provide wider crossing gaps, the corresponding increase in pedestrian speed tends to increase the difficulties of crossing. The results of the study, in the form of the probability distribution shown in Figure 3, confirm this compound effect.

Up to a module of 15 sq ft per pedestrian, the probability of pedestrian conflicts remains almost 100 percent, indicating the virtual absence of a suitable crossing gap in the mainstream traffic flow. This region also corresponds with the region of restricted walking speeds shown in Figure 2. Above an area module of 15 sq ft, there is a sharp drop in the probability of conflict as pedestrian ranks open up. However, there is also a corresponding increase in pedestrian speed, keeping the probability of conflict above the 50 percent level up to a module of about 35 sq ft per pedestrian, at which point the probability of conflict again drops sharply. At the 35-sq ft module, sufficient area is available for mainstream and cross-stream pedestrians to react in time to avoid conflict with each other. The lower probabilities of conflict associated with this higher module would be consistent with higher levels of service and pedestrian convenience.

Figure 3. Probability of conflicts for cross-flow traffic.

Pedestrian Spacing Study

The Traffic Engineering Handbook makes use of a 2-ft wide pedestrian lane for design purposes. On the basis of human shoulder breadths this might be considered a valid assumption. In the course of field studies, however, it was observed that a 2-ft pedestrian spacing was adopted intermittently and only under the densest flow conditions. In free-flow conditions most pedestrians prefer to avoid contact with others and therefore adopt larger inter-person spacings. Natural spacing in the traffic stream also determines the ease of overtaking and passing other pedestrians. To determine these natural spacings under different traffic concentrations, inter-person distances were measured on a large sample of time-lapse photographs. Figure 4 shows the results of these measurements fitted to parabolas as suggested by a somewhat similar study of sidewalks conducted by Navin and Wheeler (9).

Level-of-Service Standards for Walkways

The level-of-service standards for walkways provide a means of determining the qualitative aspect of the design environment; however, they do not eliminate the need for designer judgment. The designer must carefully examine all elements of walkway design including such traffic characteristics as the magnitude and duration of peaks, platooning caused by traffic light cycles, and all the ramifications of space utilization and cost. When designing for extreme peak demands of short duration, lower level-of-service standards may be tolerated to provide the basis for more economic design. Added consideration must be exercised in selecting design standards near maximum capacity levels because the critical pedestrian density is likely to be exceeded intermittently. When critical density is exceeded, flow volumes fall below the specified design level, and pedestrian delay and backups are likely to occur, thus requiring determination of the adequacy of holding or queuing space at the approaches to the critical section.

The proposed level-of-service standards are based on the assumption of a pedestrian module range of area occupancies per person. Each level of service is illustrated by a photograph of unidirectional flow at the approximate pedestrian area occupancy repre-

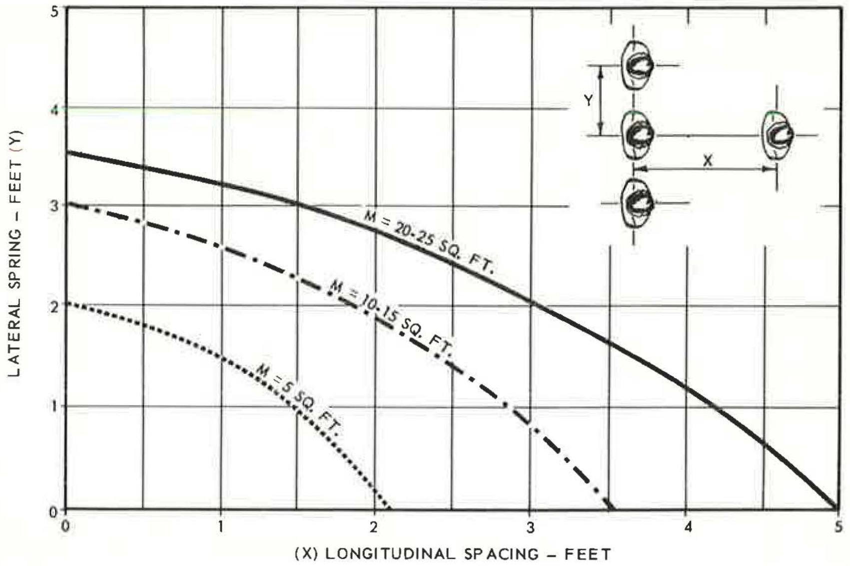

Figure 4. Longitudinal and lateral spacing of pedestrians in traffic stream.

senting that level. The photographs are supplemented by a verbal description of the qualitative aspects of each level of service in terms of the freedom to select individual walking speeds, freedom to pass, and probability of crossing conflicts. Design volumes are presented as a range, and the designer is required to exercise judgment in applying these values. If unidirectional traffic is composed of commuters or workers, the higher design volumes in a given range may be safely assumed. The lower range of design vol-

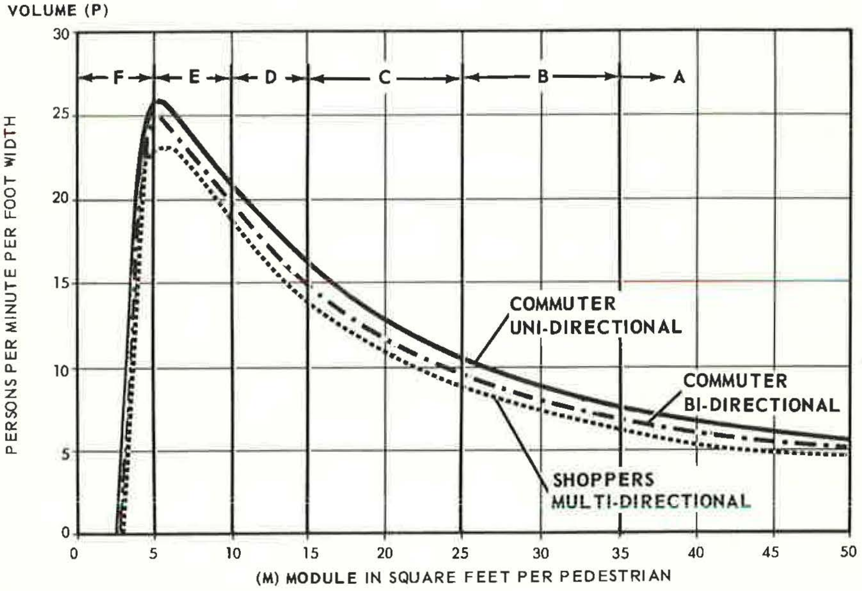

Figure 5. Level-of-service standards for walkways (volume versus module).

umes would be recommended where traffic is composed largely of shoppers or persons carrying baggage or where the traffic pattern involves cross movements, reverse flows, or other conflicts.

Level-of-Service Descriptions for Walkways

Level-of-service standards for walkways are described in the following paragraphs, and pedestrian volume and area relationships are shown in Figure 5. Figure 6 shows pedestrian concentrations at the various levels of service.

Level of Service A—Equivalent to an average pedestrian area occupancy of 35 sq ft per person or greater, at level of service A sufficient area is provided for pedestrians to select freely their own walking speed, to bypass slower pedestrians, and to avoid crossing conflicts with others. Design volumes would be approximately 7 pedestrians per minute per foot width of walkway or less. Designs consistent with this level of service would include public buildings or plazas without severe peaking characteristics or space restrictions.

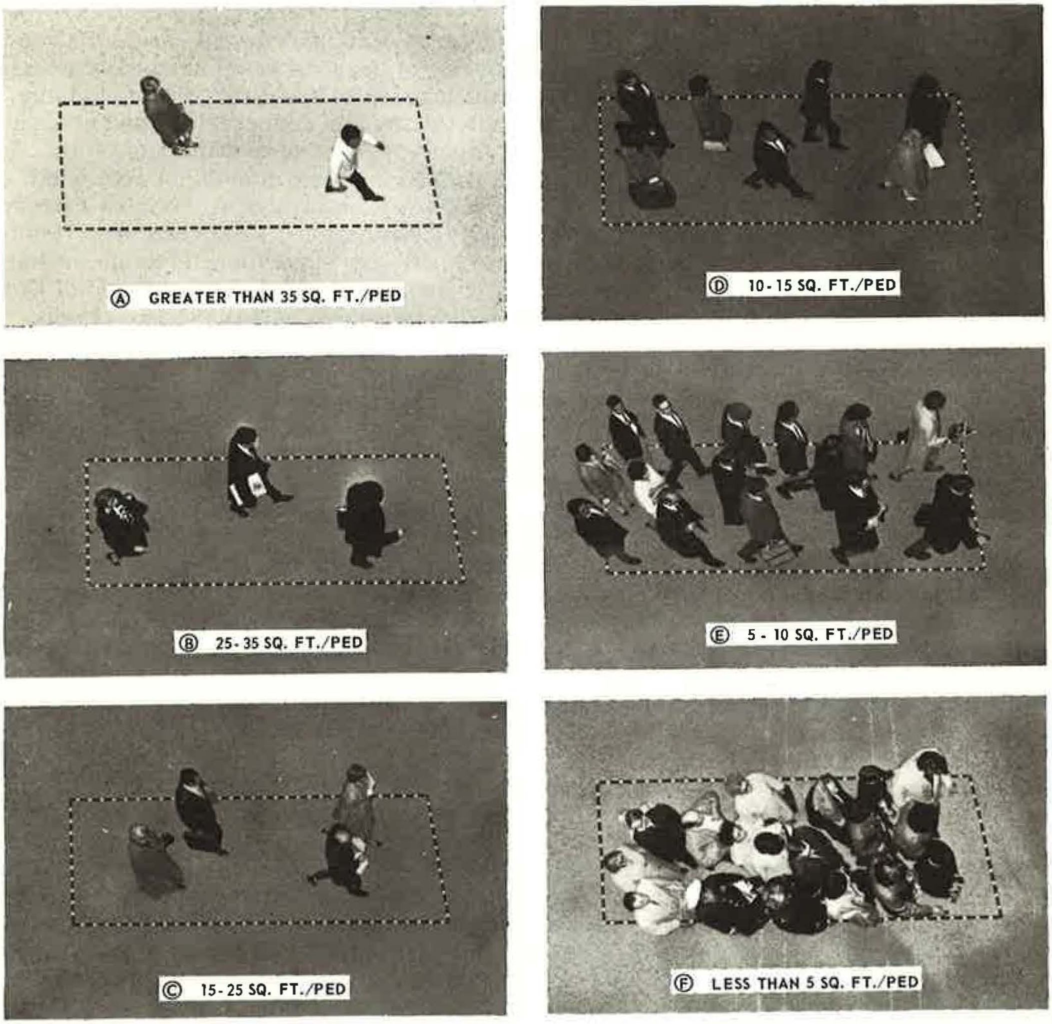

Figure 6. Levels of service for walkways.

Level of Service B—Equivalent to an average area occupancy in the range of 25 to 35 sq ft per person, at level of service B sufficient space is available to select normal walking speed and to bypass other pedestrians in primarily unidirectional flows. Where reverse direction or pedestrian crossing movements exist, minor conflicts will occur, slightly lowering mean pedestrian speeds and potential volumes. Design volumes would be in the approximate range of 7 to 10 pedestrians per minute per foot width of walkway. Designs consistent with this level of service would represent a reasonably high type of design for transportation terminals and buildings in which recurrent, but not severe, peaks are likely to occur.

Level of Service C—Equivalent to an average area occupancy in the range of 15 to 25 sq ft per person, at level of service C freedom to select individual walking speed and freely pass other pedestrians is restricted. Where pedestrian cross movements and reverse flows exist, there is a high probability of conflict requiring frequent adjustment of speed and direction to avoid contact. Design volumes would be in the range of 10 to 15 pedestrians per minute per foot width of walkway. Designs consistent with this level of service would represent reasonably fluid flow; however, considerable friction and interaction between pedestrians are likely to occur, particularly in multidirectional flow situations. Examples of this type of design would be heavily used transportation terminals, public buildings, or open spaces where severe peaking, combined with space restrictions, limit design flexibility.

Level of Service D—Equivalent to an average area occupancy in the range of 10 to 15 sq ft per person, at level of service D the majority of persons would have their normal walking speeds restricted and reduced due to difficulties in bypassing slower moving pedestrians and avoiding conflicts. Pedestrians involved in reverse-flow and crossing movements would be severely restricted, with the occurrence of multiple conflicts. Design volumes would be in the range of 15 to 20 pedestrians per minute per foot width of walkway. Designs at this level of service would be representative of the most crowded public areas, where it is necessary to continually alter walking stride and direction to maintain reasonable forward progress. At this level of service there is some probability of intermittently reaching critical density, causing momentary stoppages of flow. Designs consistent with this level of service would represent only the most crowded public areas.

Level of Service E—Equivalent to an average area occupancy in the range of 5 to 10 sq ft per person, at level of service E virtually all pedestrians would have their normal walking speeds restricted requiring frequent adjustments of gait. At the lower end of the range, forward progress would only be made by shuffling. Insufficient area would be available to bypass slower moving pedestrians. Extreme difficulties would be experienced by pedestrains attempting reverse-flow and cross-flow movements. The design volume in the range of 20 to 25 pedestrians per minute per foot width of walkway would approach the maximum attainable capacity of the walkway, with the result of frequent stoppages and interruptions of flow. Design in this range should only be employed for short peaks in the most crowded areas. This design level would occur naturally with a bulk arrival traffic pattern that immediately exceeds available capacity, and this is the only design situation for which it would be recommended. Examples would include sports stadium design or rail transit facilities where there may be a large short-term exiting of passengers from a train. When this level of service is assumed for these design conditions, the adequacy of pedestrian holding areas at critical design sections and all supplementary pedestrian facilities must be carefully evaluated.

Level of Service F—Equivalent to an average area occupancy of 5 sq ft or less per person, at level of service F all pedestrian walking speeds are extremely restricted, and forward progress can only be made by shuffling. There would be frequent unavoidable contact with other pedestrians and reverse or crossing movements would be virtually impossible. Traffic flow would be sporadic with forward progress based on movement of those in front. This level of service is representative of a loss of control and a complete breakdown in traffic flow. Pedestrian areas less than 5 sq ft are more representative of a queuing than a traffic flow situation, and this level of service is not recommended for walkway design.

PEDESTRIAN TRAFFIC FLOW ON STAIRWAYS

Human locomotion on stairways is a distinctly different activity from walking. Locomotion on stairways is restricted because of the need to overcome gravity in ascent and to safely control it in descent. In addition, the dimensional restraints imposed by the stair treads limit pacing distance, which further restricts locomotion. Because of these factors, pedestrians tolerate closer spacing on stairways than they generally do on streets.

Two time-lapse photography studies of stairways were conducted using the same techniques developed for walkways. These studies consisted of photography of ascending commuter movement at a Manhattan ferry terminal and ascending and descending movements at a sports stadium. Equations resulting from a least-squares fitting of the data were, for ascending stairways,

$$P = \frac{111M - 162}{M^2} \tag{5}$$

$$S = \frac{111M - 162}{M} \tag{6}$$

and for descending stairways,

$$P = \frac{128M - 206}{M^2} \tag{7}$$

$$S = \frac{128M - 206}{M} \tag{8}$$

where

P = volume in pedestrians per minute per foot of stairway,
S = horizontal space mean speed in feet per minute, and
M = pedestrian module in square feet area per pedestrian.

The data plot and fitted curves from the two surveys are shown in Figures 7, 8, 9, and 10. The study indicates that a pedestrian area occupancy of about 10 sq ft per person is approximately normal based on previous studies of free-flow speeds on stairs. This area module is about half that required for normal walking.

The critical pedestrian area modules of 2.9 and 3.2 sq ft derived from the two surveys are about equal to a 2 stair-tread length, human-shoulder-width area. The zero movement area of 1.5 and 1.6 ft determined by the curve fitting is equivalent to human occupancy of one tread. At an area of 10 sq ft the pedestrian zone is estimated to be about 4 to 5 stair-treads long and 2½ ft wide. This would give sufficient room for reasonably normal stair locomotion but not enough freedom to bypass slower pedestrians. Using the 2 shoulder-width spacing criterion for bypassing others, lateral spacing would have to expand to 4 ft or more, giving an estimated area for bypassing slower moving pedestrians of about 20 sq ft.

The maximum flow volumes of 18.9 persons per minute per foot of stair width ascending and 20.0 descending developed by the time-lapse photography study compares with values of 19 and 21 recommended by Hankin and Wright as design criteria for the London subways. The New York City Transit Authority reports a design capacity of 1,000 persons per hour per foot width for stairways (16.7 PPMFT) and the Massachusetts Bay Transit Authority a design value of 20 persons per foot width per minute (8).

The results shown by this study indicate that all these design values, with the exception of the New York Transit Authority, occur at the critical region of pedestrian traffic flow equivalent to an area occupancy of about 3 sq ft per person. Use of design values at this level of pedestrian area occupancy shows little regard for comfortable human requirements of stair locomotion, which would require an open area of at least 3 stair treads in length and one human shoulder in width, or an area of at least 5 to 6 sq ft per person.

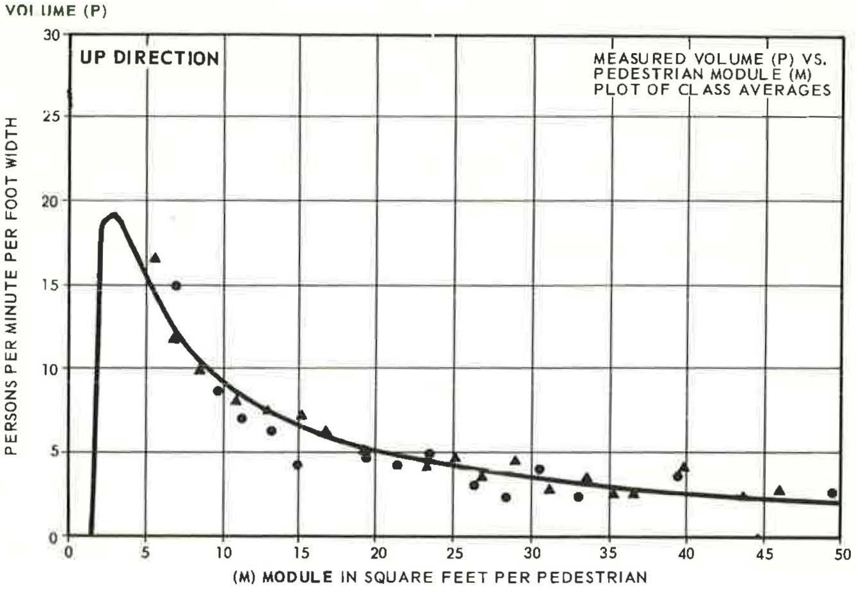

Figure 7. Pedestrian volume versus space for traffic moving up on stairways.

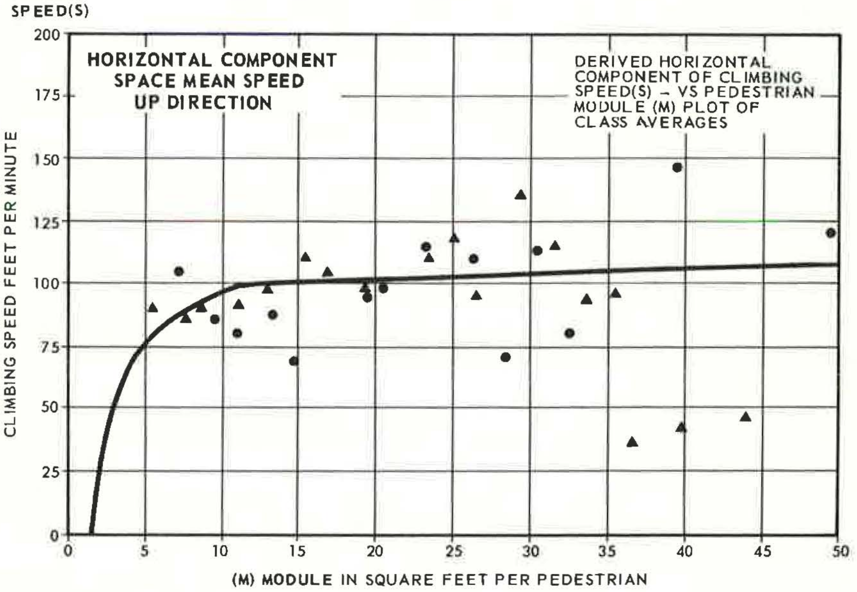

Figure 8. Pedestrian speed versus space for traffic moving up on stairways.

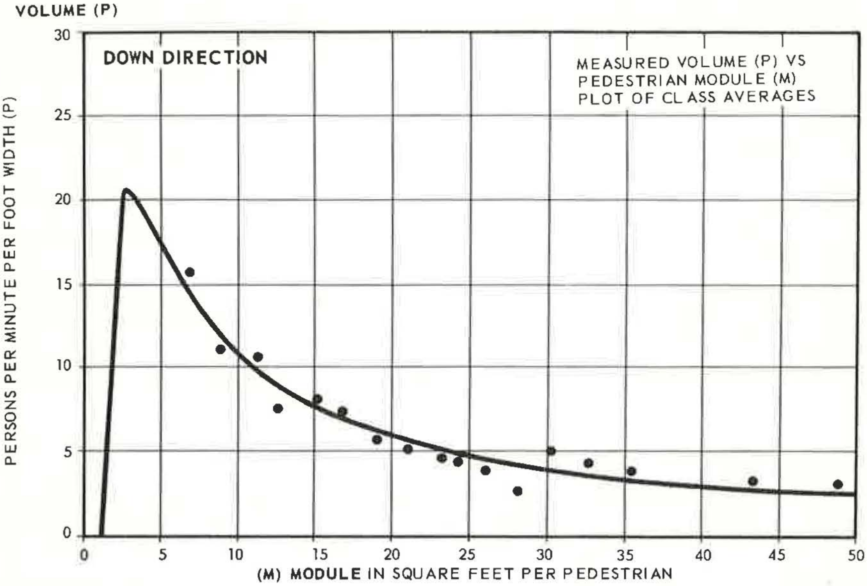

Figure 9. Pedestrian volume versus space for traffic moving down on stairways.

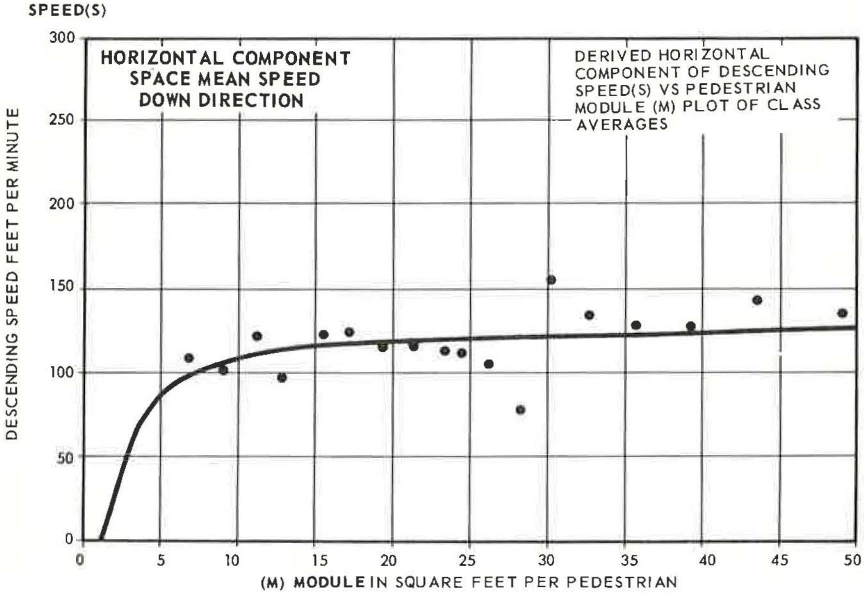

Figure 10. Pedestrian speed versus space for traffic moving down on stairways.

Level-of-Service Standards for Stairways

In designing stairways, increased consideration must be given to the role of human characteristics because of the greater safety hazards and energy expenditure required in stair locomotion. In addition to the exercise of designer judgment in evaluating traffic patterns and peaking characteristics recommended in using walkway standards, the following factors should be considered in stair design:

1. Stairways should be well lighted and provided with sufficient headroom, properly designed and maintained riser and tread configurations, and railings;
2. Stairways should be located so as to be readily visible and identifiable as a means of direct access to the levels they are designed to interconnect;
3. Riser heights should be kept below 7 in. to reduce human energy expenditure and to increase traffic efficiency;
4. Stairways should be offset from mainstream traffic to avoid pedestrian conflicts;
5. Clear areas sufficiently large to allow for queuing pedestrians should be provided at the top and bottom of all stairways; and
6. When a stairway is placed directly within a corridor, the lower capacity of the stairway is the controlling factor in the design of the section.

Level-of-Service Descriptions for Stairways

Level-of-service standards for stairways are described in the following paragraphs, and pedestrian volume and area relationships are shown in Figure 11. Figure 12 shows pedestrian concentrations at the various levels of service.

Level of Service A—Level of service A is equivalent to an average pedestrian area occupancy of 20 or more sq ft per person and a volume of approximately 5 or fewer pedestrians per minute per foot width of stairway. This area occupancy represents a space more than 5 treads long and 4 ft wide. At this level of service, sufficient area is provided to select freely stair locomotion speed and to bypass slower moving pedestrians. No difficulties would be experienced with reverse traffic flows. Designs at this level of service would be consistent with public buildings or plazas that have no severe traffic peaks or space limitations.

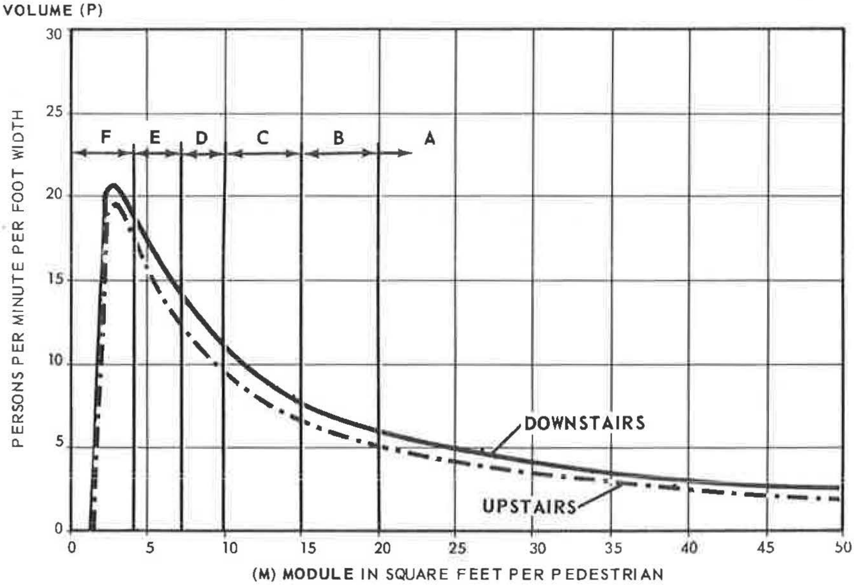

Figure 11. Level-of-service standards for stairways (volume versus module).

Level of Service B—Level of service B is equivalent to an average area occupancy of between 15 and 20 sq ft per person and a volume of 5 to 7 pedestrians per minute per foot width of stairway. This area occupancy represents a space 5 treads long and 3 to 4 ft wide. Virtually all persons may freely select stair locomotion speeds. However, in the lower range of area occupancy, some difficulties would be experienced in passing slower moving pedestrians. Reverse flows would not present a serious traffic conflict. Designs at this level of service would be consistent with transportation terminals and public buildings that have recurrent peak demands and no serious space limitations.

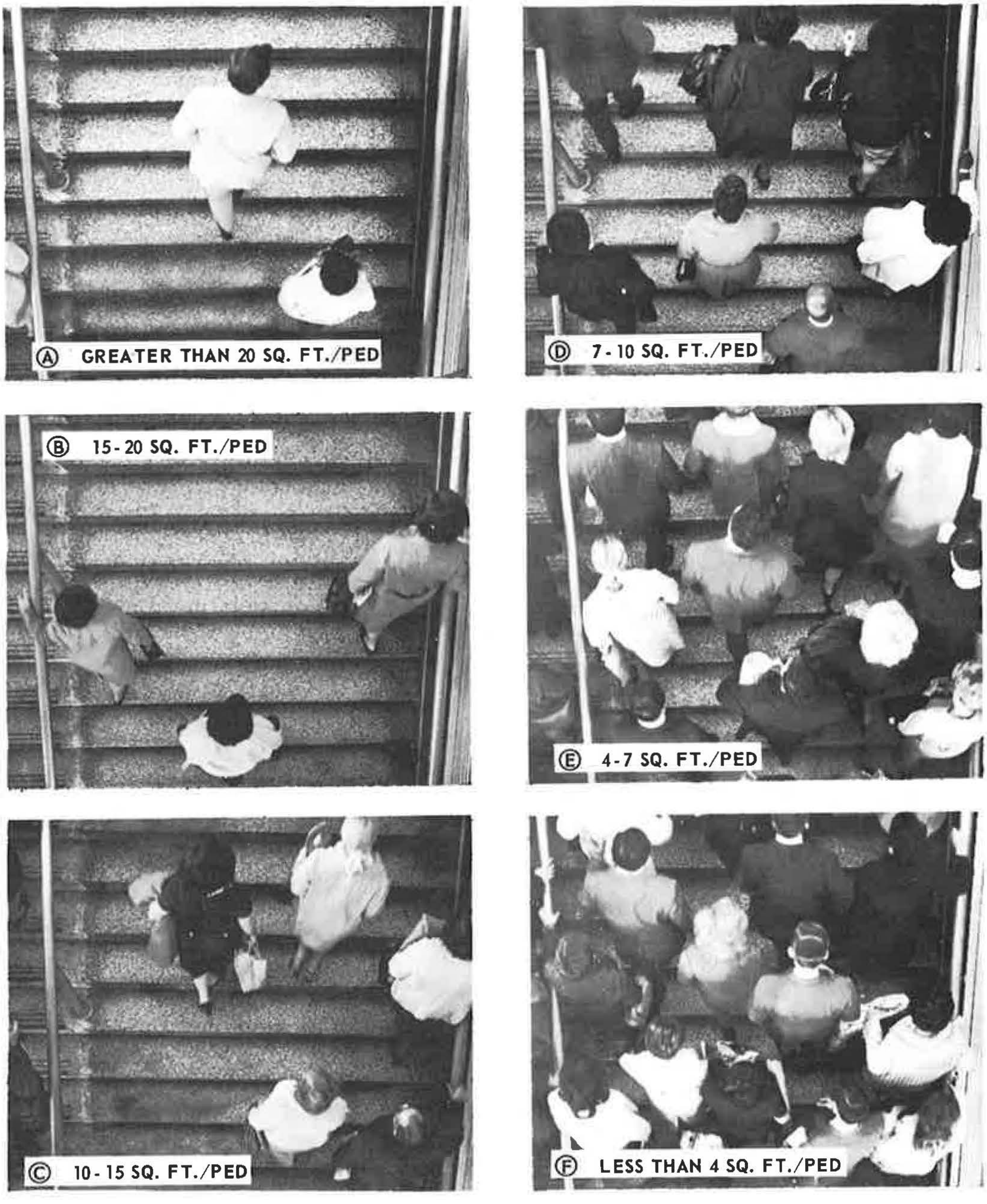

Figure 12. Levels of service for stairways.

Level of Service C—Level of service C is equivalent to an average area occupancy of 10 to 15 sq ft per person and a volume range of 7 to 10 pedestrians per minute per foot width of stairway. This area occupancy represents a space 4 to 5 treads long and about 3 ft wide. At this level of service stair locomotion speed would be restricted slightly due to the inability to pass slower moving pedestrians. Serious conflicts would not be encountered with reverse flows. Design at this level of service would be consistent with transportation terminals and public buildings with recurrent peak demands and some space restrictions.

Level of Service D—Level of service D is equivalent to an average area occupancy of 7 to 10 sq ft per person and a volume range of 10 to 13 pedestrians per minute per foot width of stairway. This area occupancy represents a space 3 to 4 treads long and 2 to 3 ft wide. At this level of service, stair locomotion speeds would be restricted for the majority of persons due to the inability to pass slower moving pedestrians and the limited open tread space ahead. Reverse flows would encounter some conflicts. Designs at this level of service would be consistent with more crowded public buildings and transportation terminals subjected to relatively severe peak demands.

Level of Service E—Level of service E is equivalent to an average area occupancy of 4 to 7 sq ft per person and a volume of 13 to 17 pedestrians per minute per foot width of stairway. This area occupancy represents a space 2 to 4 tread lengths long and 2 ft wide, or the minimum possible area for stair locomotion. At this level of service, virtually all persons would have their normal stair locomotion speeds reduced because of the minimum tread length space and the inability to bypass others. Intermittent stoppages are likely to occur as the critical pedestrian density is reached. Reverse flows would experience serious conflicts. This level of service would only occur naturally with a bulk arrival traffic pattern that immediately exceeds available capacity, and this is the only design situation for which it would be recommended. Examples would include sports stadiums or transit facilities where there is a large, uncontrolled short-term exodus of pedestrians.

Level of Service F—Level of service F is equivalent to an average area occupancy of 4 sq ft per person or less. This area occupancy is representative of a complete breakdown in traffic flow, with many stoppages. Forward progress would depend on movement of those in front. This level of service is not recommended for design.

ACKNOWLEDGMENTS

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INVESTIGATION OF THE CAPACITY OF THE WHITE HOUSE SIDEWALK FOR ORDERLY DEMONSTRATIONS

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The objective of this study was to determine the maximum number of demonstrators that could congregate in an orderly manner on the sidewalk bordering the south side of Pennsylvania Avenue, N.W., in front of the White House in Washington, D.C., without impeding the normal flow of pedestrian traffic. The procedure used was to estimate the maximum number of pedestrians that would use the White House sidewalk during peak periods of demand throughout the year. Estimates were then made to determine the amount of sidewalk space that could accommodate that maximum pedestrian demand without causing discomfort or loss of mobility. The remaining sidewalk space was then investigated to estimate the maximum number of demonstrators it could accommodate for three different kinds of demonstrations: (a) a "circulating" demonstration, in which a set number of demonstrators would continuously circulate on the sidewalk at varying rates of speed; (b) a "stationary" demonstration, in which a fixed number of demonstrators would stand, without movement, on the White House sidewalk at varying degrees of concentration; and (c) a "walk-by" demonstration, in which large groups of demonstrators would walk by the White House, without returning, at varying rates of speed for certain periods of time.

•PUBLIC sidewalks, especially those located near prominent government buildings, are being used more and more frequently as sites for demonstrations. Public officials, in an effort to satisfy the demands of the groups wishing to demonstrate and at the same time to ensure the use of the sidewalk for regular pedestrian traffic, have in some instances set up limitations on the number of demonstrators allowed to use a site.

The objective of this study is to determine the maximum sidewalk area that can be allocated for use by orderly demonstrators without disrupting the normal pedestrian flow. Given this area, estimates are made of the maximum number of demonstrators that can congregate in the given space for three types of demonstrations: circulating, stationary, and walk-by.

The site chosen for the study was the sidewalk bordering the south side of Pennsylvania Ave., N.W., in front of the White House, in Washington, D.C. This sidewalk is frequently used for demonstrations and at the present time has restrictions on the number of demonstrators allowed to congregate there.

Information on the pedestrian characteristics on the White House side is obtained from the studies conducted by the District of Columbia Department of Highways and Traffic and from observations at the site. The data collected were subjected to statistical analysis, and the results were used to estimate pedestrian flows and densities.

DATA COLLECTION

The dimensions of the White House sidewalk were obtained by on-the-spot observations and from a map supplied by the National Park Service. The sidewalk in front of the White House extends along the south side of Pennsylvania Avenue between East Executive Avenue and West Executive Avenue. It is bordered on the south, or White House

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Sponsored by Committee on Pedestrians and presented at the 50th Annual Meeting.

7. Hankin, B. D., and Wright, R. A. Passenger Flow in Subways. Operational Research Quarterly (Great Britain), Vol. 9, No. 2, 1958, pp. 81-88.
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side, by a stone and iron fence that circles the White House grounds, and on the north, or roadway side, by a concrete curb and at certain places by a 4-ft high, single-strand, heavy wire cable barrier. Two driveways cross the sidewalk: at the east gate, approximately 140 ft west of East Executive Avenue, and at the west gate, approximately 130 ft east of West Executive Avenue. Three trees are located at or near the center longitudinal axis of the sidewalk approximately 31 ft, 44 ft, and 75 ft west of East Executive Avenue.

Figure 1 shows the dimensions of the White House sidewalk as 775 ft long and 37.5 ft wide. However, approximately 45 ft should be subtracted from the length of the sidewalk to account for driveways crossing the sidewalk and for adjacent sidewalk traffic. Approximately 2.5 ft should be subtracted from its width to account for the stone and iron fence and occasional single-strand wire fence that border each side of the sidewalk. The sidewalk area actually available to pedestrians and demonstrators, therefore, is 730 ft long and 35 ft wide—an area of 25,500 sq ft.

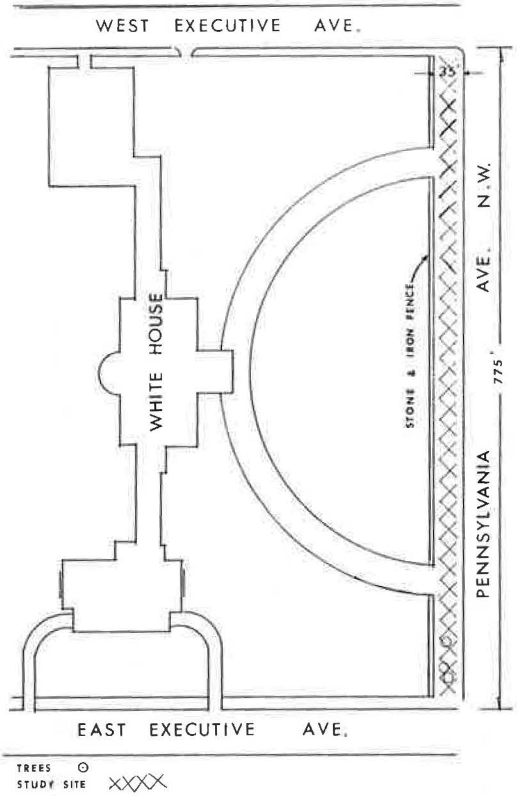

Figure 1.

To determine the number of pedestrians using the White House sidewalk and the rates at which they travel, two observers were stationed on the stone wall bordering the inside of the sidewalk for three consecutive days: Wednesday, October 16, 1968; Thursday, October 17, 1968; and Friday, October 18, 1968. Counts were made during two time periods—10:30 a.m. to 2:00 p.m. and 4:00 to 6:00 p.m. During these time periods, according to District of Columbia Highway Department surveys, the peak volumes of pedestrian traffic in the White House area occur.

To determine the average pedestrian walking speed, one observer randomly selected persons moving along the sidewalk and used a stopwatch to measure the length of time each took to cover a 100-ft course. To determine the number of pedestrians using the sidewalk the other observer counted all pedestrians passing over a certain point on the sidewalk during 15-min intervals. Both observers segregated the pedestrians into two groups: "normal pedestrians" (workers, shoppers, etc.) and "tourists." The factors by which tourists were separated from normal pedestrians are not, of course, clearly and easily articulated. In general, however, persons who wore business or work clothing, walked by themselves, did not look around at the White House or Lafayette Park, did not carry cameras, and moved rapidly as if with some specific destination were categorized as normal pedestrians. Persons who wore casual clothing, walked in groups of women or children, carried cameras, took photographs, or moved in a casual and relaxed manner were categorized as tourists. When persons stopped for some reason after entering the study area, their elapsed time and apparent purpose for stopping was noted. Because these persons were few in number, they were not included in the survey.

The traffic flow patterns of tourists entering and leaving the White House grounds on conducted tours were also noted. All White House tour visitors currently enter the grounds by a side entrance on East Executive Avenue and generally leave by the east gate on Pennsylvannia Avenue. Because the visitors receive a clear view of the White

House during the tour and the tourist parking lots are situated behind the White House in the opposite direction from the sidewalk, very few of them turn left at the east gate and walk along the sidewalk in front of the White House to take pictures or to obtain a different view. On the contrary, the vast majority of visitors turn right at the east gate and walk to the corner of East Executive Avenue to the visitors' parking lot behind the White House grounds. Only a small percentage of tourists observed stopped on the White House sidewalk, and those remained standing only briefly to take one or two pictures.

DETERMINING SIDEWALK SPACE NECESSARY FOR EXISTING PEDESTRIAN DEMAND

One objective of this study was to determine how much sidewalk space is necessary to accommodate the maximum number of pedestrians passing over the sidewalk in an orderly manner during the busiest periods of the day. This space requirement is a function of three basic factors: the number of persons using the sidewalk; the speed at which the average pedestrian travels; and the degree to which pedestrians are concentrated per square foot of sidewalk space (otherwise expressed as the pedestrian "concentration" or "K" factor). These three factors, when combined, may be expressed as the variable "total pedestrian flow," i.e., the number of pedestrians that can cross a certain point on a sidewalk during certain periods of time. For convenience, this figure is normally expressed per foot of sidewalk width. Once these three factors are calculated, the total pedestrian flow per hour per foot of sidewalk width can be determined.

Number of Pedestrians Using Sidewalk During Peak Summer Months

In general, the normal pedestrian flow comprised of workers, shoppers, and local businessmen does not vary during different times of the year. However, the numbers of tourists visiting Washington, and therefore the White House area, are highly seasonal. The actual pedestrian counts conducted for this study were made in October 1968. For this reason the figures obtained must be adjusted upward to account for the substantially higher numbers of tourists that would use the White House sidewalk during the summer months. The normal pedestrian figures are treated as constant throughout the year.

Surveys obtained from the District of Columbia Highway Department indicate that the highest pedestrian flows across intersections in the vicinity of the White House occur from 11:00 a.m. to 1:00 p.m., 1:00 to 2:00 p.m., and 5:00 to 6:00 p.m. (Table 1). Accordingly, the White House sidewalk pedestrian counts obtained for this survey on October 16, 17, and 18 were conducted during these time periods.

TABLE 1

HOURLY VARIATION IN PEDESTRIAN VOLUMES AT PENNSYLVANIA AVENUE AND EAST EXECUTIVE DRIVE

Time Period	Hourly Flow of Pedestrians	
	August 8, 1963	April 6, 1966
7-8 a.m.	146	191
8-9	621	671
9-10	790	668
10-11	1,480	1,124
11-12	1,426	1,674
12-1 p.m.	618	1,697
1-2	600[a]	1,000[a]
2-3	275	472
3-4	217	291
4-5	313	273
5-6	828	188

Source: Pedestrian counts conducted by District of Columbia Department of Highways.

[a] Estimated; 1:00 to 2:00 p.m. was lunch hour for counters.

During the highest 15-min time segment in each of the three time periods for these days in October, 500 pedestrians were counted during the 11:00 a.m. to 1:00 p.m. period, 275 during the 1:00 to 2:00 p.m. period, and 240 during the 5:00 to 6:00 p.m. period. During the 11:00 a.m. to 1:00 p.m. and 1:00 to 2:00 p.m. periods, tourists comprised approximately 20 percent of all pedestrians; during the 5:00 to 6:00 p.m. period, tourists comprised 10 percent of all pedestrians. Of 500 pedestrians counted during the peak 15 min within the busiest 11:00 a.m. to 1:00 p.m. period, therefore, 100 were tourists—a ratio of 4 normal pedestrians to 1 tourist.

Because the number of tourists visiting Washington during October is somewhat less than during certain peak summer months, it was necessary to adjust the October figures. The number of White House visitors during

TABLE 2

NUMBER OF PERSONS VISITING WHITE HOUSE

Month	1967	1968
January	35,000	32,000
February	48,000	56,000
March	127,000	100,000
April	205,000	150,000
May	195,000	100,000
June	240,000	72,000
July	247,000	156,000
August	257,000	191,000
September	115,000	83,000
October	115,000	94,000
November	85,000	77,000
December	70,000	65,000

Source: Joseph A. Bruno, Group Tour Director, The White House. Figures are rounded to the nearest thousand.

TABLE 3

MAXIMUM NUMBER OF PEDESTRIANS USING WHITE HOUSE SIDEWALK DURING BUSIEST TIME OF YEAR

Factor	11 a.m. - 1 p.m.	1 p.m. - 2 p.m.	5 p.m. - 6 p.m.
15-min peak	500	275	240
Percentage of tourists	20	20	10
Number of tourists	100	55	24
Adjustment factor	3	3	3
Projected number of tourists for 15-min peak	300	165	72
Number of normal pedestrians for 15-min peak	400	220	216
Total pedestrians for 15-min peak	700	385	288
Total pedestrians per hour	2,800	1,540	1,152
Design flows	3,260	1,848	1,382

August 1967 was 257,000; the number for October 1968 was 94,000 (Table 2). Accordingly, one can reasonably predict that during an average month of August, 2.7 or 3 (rounded) times as many persons would visit the White House as in October. Assuming that the October peak 15-min period count of 400 normal pedestrians would remain relatively constant throughout the year, the October count of 100 tourists during the same 15-min period must be increased by this factor of 3. Thus, a projected figure for a peak 15-min period during a normal month of August would include 400 normal pedestrians and 300 tourist pedestrians, a ratio of 4 to 3. An hourly figure of 2,800 pedestrians is obtained by multiplying by 4. To allow for future growth, the projected figure of 2,800 pedestrians per hour over the White House sidewalk during the peak summer month of August was further adjusted upward by 20 percent to yield a "design flow" figure of 3,260 pedestrians per hour. The calculations are given in Table 3.

It should be noted that this design flow figure of 3,260 pedestrians per hour over the White House sidewalk is many times greater than the average number of pedestrians actually using the sidewalk during most of the year.

TABLE 4

OBSERVED NORMAL PEDESTRIAN SPEEDS ON WHITE HOUSE SIDEWALK

Time Required to Walk 100 ft (sec)	No. of Persons Walking at Various Speeds (N)	Speed (fps) (S)	S × N
13	4	7.7	30.8
15	25	6.7	167.5
17	27	5.8	156.6
19	48	5.3	254.4
21	47	4.8	225.6
23	29	4.3	124.7
25	17	4.0	68.0
27	9	3.7	33.3
29	3	3.4	10.2
33	1	3.0	3.0
Total	210		1,074.1

Sum of persons observed = 210

Sum of S × N = 1,074.1

Average speed $= \frac{\text{Sum of S} \times \text{N}}{\text{Sum of persons observed}}$

$= \frac{1{,}074.1}{210} = 5.1$ fps

Pedestrian Walking Speeds

Average walking speeds were first calculated separately for normal pedestrians and for tourists. Based on a sample of 210 normal pedestrians walking along a 100-ft course laid out on the White House sidewalk (Table 4), it was found that the average normal pedestrian walks at a rate of 5.1 feet per second (fps). This rate of 5.1 fps is slightly higher than speeds recorded by other pedestrian studies. The Traffic Engineering Handbook (2), for example, gives a rate of 4.2 fps; Hoel (6) gives 4.8 fps; Wheeler and Navin (1) give 4.5 fps; and MacDorman (8) gives 4.6 fps. The higher average speeds measured at the White House no doubt reflect in large part the lack of distractions and window-shoppers otherwise prevalent where many retail stores line the sidewalks.

Similar calculations, based on a sample of 162 tourists walking over a 100-ft course, revealed an average walking speed of 3.2 fps (Table 5).

The average rate of travel per average pedestrian, therefore, depends on the relative proportions of normal pedestrians and tourists in the total flow. During the 11:00 a.m. to 1:00 p.m. period in the peak summer months, the ratio of normal pedestrians to tourists is 4 to 3. Thus, the rate of travel for the average individual pedestrian is calculated by multiplying the proportion of normal pedestrians by their average rate of speed (4 × 5.1 = 20.4), multiplying the proportion of tourists by their average rate of speed (3 × 3.2 = 9.6), adding the two products together (20.4 + 9.6 = 30.0), and then dividing by 7 to obtain the rate of speed per person (30.0 ÷ 7 = 4.3). Given the proportion of tourists to normal pedestrians present during the peak summer months, the average pedestrian crossing the White House sidewalk travels at an average rate of 4.3 fps.

TABLE 5

OBSERVED TOURIST SPEEDS ON WHITE HOUSE SIDEWALK

Time Required to Walk 100 ft (sec)	No. of Persons Walking at Various Speeds (N)	Speed (fps) (S)	S × N
20	6	5.0	30.0
25	38	4.0	152.0
30	45	3.3	148.5
35	40	2.9	116.0
40	1	2.5	40.0
45	3	2.2	6.6
50	6	2.0	12.0
55	8	1.8	14.4
Total	162		519.5

Sum of persons observed = 162

Sum of S × N = 519.5

$$\text{Average speed} = \frac{\text{Sum of } S \times N}{\text{Sum of persons observed}} = \frac{519.5}{162} = 3.2 \text{ fps}$$

Number of Pedestrians Per Square Foot

Each moving pedestrian occupies per second an area that is defined by his size and walking speed. When the concentration of pedestrians in a given area increases beyond a certain optimum point, forward movement becomes increasingly limited by the presence of people to the front and side. On the other hand, increases in concentration up to that optimum point increase the quantity of pedestrians that can move past a given point during any period of time. The degree of pedestrian concentration is a function of the number of square feet occupied by each moving pedestrian, and is typically designated as the K factor. Thus, a concentration of 1 pedestrian per 10 sq ft may be expressed in terms of 0.1 pedestrian per sq ft. Mathematically, this figure is conveniently stated as a K factor of 0.1.

Wheeler and Navin (1) in a recent study have described the relationship between pedestrian walking speeds and concentrations. This study, conducted on college campuses, shows that, the faster a pedestrian walks, the more space he needs. Conversely, higher concentrations of pedestrians must move at relatively slower speeds. More significantly, the study shows that pedestrians concentrated at K factors of as much as 0.1 pedestrian per sq ft can move at speeds up to and above 4.3 fps. A K factor of 0.05 pedestrian per sq ft would give a pedestrian 20 sq ft in which to walk and would allow for free and easy movement. A K factor of 0.1 pedestrian per sq ft, which would give a pedestrian 10 sq ft in which to walk, would be somewhat more confined but offers a more efficient concentration at which to move masses of people. In general, therefore, pedestrians moving at 4.3 fps can be efficiently grouped together in concentrations as high as 0.1 pedestrian per sq ft. The results of the Wheeler and Navin study are shown in Figure 2.

Pedestrian Flow

The flow of pedestrian traffic is the number of pedestrians that can pass over a given point during a specific period of time with varying degrees of concentration and at varying rates of speed for each foot of sidewalk width. The flow of traffic may be expressed mathematically by the equation $Q = K \times U \times T$, where Q is the flow of pedestrian traffic, K is the density of pedestrian concentration per square foot of sidewalk space, U is the average speed of the pedestrian movement, and T is the time period involved. Thus, using 0.1 as the optimum pedestrian concentration (K) for efficient movement of pedestrian traffic, 4.3 fps as the average walking speed (U) of the typical White House pedestrian, and 3,600 sec, or 1 hour, as the time period (T) involved, it is apparent that approximately 1,548 pedestrians can walk along the White House sidewalk in an orderly manner for each foot of sidewalk width during an hour:

$$Q = 0.1 \times 4.3 \times 3{,}600 = 1{,}548$$

The equivalent figure for a concentration (K) of 0.075 pedestrian per sq ft is 1,161; for a concentration of 0.05 pedestrian per sq ft, the figure is 774.

These figures are based on a one-way traffic flow. The studies of Wheeler and Navin have shown, however, that the sidewalk capacity is reduced by the friction created when two streams of pedestrian traffic move in opposite directions. When the pedestrian flow is split evenly, with 50 percent moving in one direction and 50 percent moving in the other, there is a 4.0 percent loss of sidewalk capacity relative to the one-way flow. This would reduce the White House sidewalk traffic flows to 1,486 pedestrians per hour per foot of sidewalk width for a concentration of 0.1 pedestrian per sq ft, 1,115 for a concentration of 0.075 pedestrian per sq ft, and 743 for a concentration of 0.5 pedestrian per sq ft.

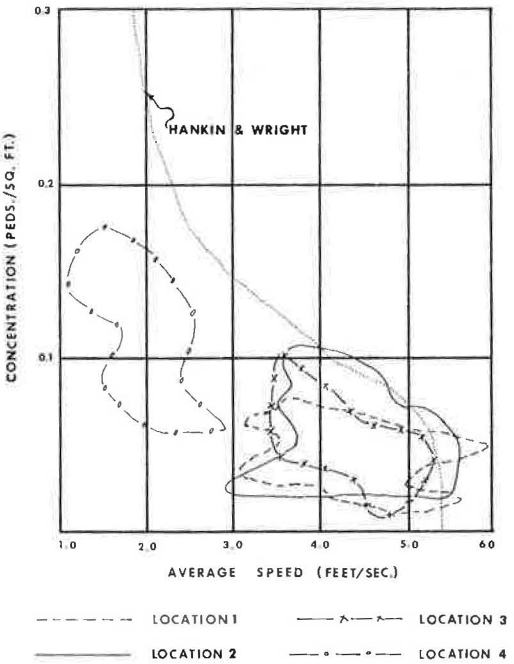

Figure 2.

To determine the width of a traffic lane for the peak pedestrian summer traffic on the White House sidewalk, one need only multiply these flow or Q figures by different sidewalk widths. Table 6 gives the number of pedestrians that can move along the White House sidewalk per hour, in a two-way flow, for sidewalk widths of 5 ft, 7.5 ft, and 10 ft at pedestrian concentrations of 0.05, 0.075, and 0.1 pedestrian per sq ft.

In sum, design flow projection of 3,260 pedestrians per hour for the peak pedestrian traffic over the White House sidewalk during the summer months could be accommodated in a 5-ft wide traffic lane bordering the curb of Pennsylvania Avenue. If 3,715 pedestrians per hour moved along this 5-ft traffic lane, they might comfortably be dispersed at a pedestrian concentration (K factor) of approximately 0.05 pedestrian per sq ft, i. e., a concentration of one pedestrian for every 20 sq ft. Assuming the average pedestrian requires approximately 2 ft of sidewalk width in which to walk, a 5-ft traffic lane could accommodate two 2-ft streams of pedestrian traffic, each moving in the opposite direction, with an extra foot in between for clearance. Each pedestrian would occupy a moving traffic zone of 20 sq ft—an area approximately 2 by 10 ft. At the most efficient concentration of 0.1 pedestrian per sq ft, the 5-ft wide traffic lane could accommodate up to 7,430 pedestrians per hour. At this concentration of 0.1 pedestrian per sq ft, a 5-ft wide traffic lane could handle over 4,000 more pedestrians than the 3,360 pedestrians actually using the White House sidewalk during the peak summer months and could accommodate over 6,000 more pedestrians than the 1,382 persons actually using the sidewalk during the peak summer 5:00 to 6:00 p.m. period.

DETERMINING NUMBER OF DEMONSTRATORS THAT CAN BE ACCOMMODATED

The White House sidewalk has a usable width of approximately 35 ft. A 5-ft wide pedestrian traffic lane would leave 30 ft of width for demonstrators, a traffic lane of 7.5 ft would leave 27.5 ft, and a traffic lane of 10 ft would leave 25 ft. Since the usable length of the White House sidewalk is 730 ft, the three areas available for demonstrations are 25,075 sq ft, 21,900 sq ft, and 18,250 sq ft respectively.

The remainder of this study is devoted to determining the maximum number of orderly demonstrators that can be accommodated on the available space on the White House sidewalk for three basic types of demonstration—circulating, stationary, and walk-by.

TABLE 6

NUMBER OF PEDESTRIANS PER HOUR THAT CAN MOVE ALONG VARYING WIDTHS OF SIDEWALK AT VARYING CONCENTRATIONS

Sidewalk Width (ft)	Pedestrian Concentrations		
	0.05 per sq ft	0.075 per sq ft	0.1 per sq ft
5	3,715	5,757	7,430
7.5	5,573	8,363	11,145
10	7,430	11,150	14,860

Circulating Demonstrations

A circulating demonstration is one in which a constant number of demonstrators congregate in a specific area and circulate through that area at varying rates of speed. The basic technique used to determine how many demonstrators can occupy a given area of sidewalk space at any instant in time is to multiply the varying degrees of pedestrian concentration (the K factor) by the space (feet) available. However, the degrees of pedestrian concentration vary with the speed at which demonstrators walk; the faster they move, the more space is required.

Wheeler and Navin have determined how many pedestrians actually do move along each foot of sidewalk space per minute at varying rates of speed. Their results were obtained from computations based on actual data, and their optimum flows are recorded flows, not projected flows. From their flow-speed chart, summarized in Table 7, the numbers of pedestrians that can pass a given point for each foot of sidewalk space can be determined for different walking speeds.

The values in Table 6 provide all the necessary information for the standard flow equation ($Q = K \times U \times T$) except for K, the pedestrian concentration per square foot of space, which may be computed by rearranging the flow equation:

$$K = \frac{Q}{U \times T}$$

Using the speed and flow figures in Table 6 and using 60 sec or 1 min for T, the K factors are given in Table 8. These K factors, when multiplied by the total area available, will give the number of orderly pedestrians that the area can accommodate at various rates of speed. The results of this computation for 35 ft of sidewalk width (25,550 sq ft), 30 ft of sidewalk width (21,900 sq ft), 27.5 ft of sidewalk width (20,075 sq ft), and 25 ft of sidewalk width (18,250 sq ft) are given in Table 9.

The densities, speeds, and other pedestrian characteristics in Table 9 are not based on demonstration situations. Because there are no available studies of actual demonstrations, it is not possible within this study to determine whether the speeds, densities, and other characteristics of pedestrians in demonstrations are the same as, or different from, normal pedestrian characteristics. If demonstrators walk more rapidly they would need additional room, and the estimates and figures in Table 9 would have to be decreased. If, on the other hand, demonstrators walk more slowly or at greater densities, these figures might have to be increased.

TABLE 7

NORMAL PEDESTRIAN FLOW FOR VARYING RATES OF SPEED

Walking Speed (fps)	Flow (pedestrians per min per ft of width)
4.0	27
3.0	26
2.0	22
1.0	12

TABLE 8

NORMAL PEDESTRIAN FLOW FOR VARYING RATES OF SPEED AND DEGREES OF CONCENTRATION

Walking Speed (fps)	Flow (pedestrians per min per ft of width)	K
4.0	27	0.11
3.0	26	0.14
2.0	22	0.18
1.0	12	0.20

TABLE 9

NUMBER OF ORDINARY PEDESTRIANS ACCOMMODATED WITH VARYING AMOUNTS OF SIDEWALK SPACE AT VARYING CONCENTRATIONS

Walking Speed (fps)	Degrees of Concentration (K)	Width and Area of Sidewalk			
		25 ft (18,250 sq ft)	27.5 ft (20,075 sq ft)	30 ft (21,900 sq ft)	35 ft (25,550 sq ft)
4.0	0.11	2,008	2,208	2,409	2,811
3.0	0.14	2,555	2,811	3,066	3,577
2.0	0.18	3,285	3,614	3,942	4,599
1.0	0.20	3,650	4,015	4,380	5,110

Stationary Demonstrations

A stationary demonstration is one in which a fixed number of demonstrators remain standing in a certain area with little or no movement or circulation.

In general, a larger number of demonstrators can stand within a given area than can move about or circulate within that same area for the simple reason that a moving person requires more space per second than does one who is stationary. The two variables necessary to calculate the maximum number of demonstrators that can stand in a given area are the amount of space allotted to the demonstration and the level of concentration at which the demonstrators can be grouped together.

The space available for demonstrations on the White House sidewalk has already been determined. The complete absence of a traffic lane would leave 25,550 sq ft for demonstrations; a pedestrian traffic lane 5 ft wide would leave 21,900 sq ft; and a 10-ft traffic lane would leave 18,250 sq ft.

The concentration factor, or number of square feet to be allotted to each demonstrator, is perhaps most accurately determined by reference to studies analyzing the amount of space necessary for passengers waiting for buses in loading zones and sidewalk queues. One survey conducted by the Institute of Traffic Engineers discovered that the space allotted by various city, county, and state traffic planning organizations to queuing pedestrians varied from 2.3 to 6.0 sq ft per person. The Traffic Engineering Handbook (2) estimates that for double queues approximately 2.8 sq ft should be allotted to each standing person. Because the average demonstrator is probably willing and prepared to relinquish some of the room he would otherwise expect as a normal pedestrian, the extent to which demonstrators may be concentrated, for purposes of this study, may be selected from the lower end of this range of estimates. The number of demonstrators that can stand within the four different areas of the White House sidewalk space at varying degrees of concentration are given in Table 10. Allocating 2.5 sq ft to each demonstrator, the entire White House sidewalk can accommodate 10,220 standing demonstrators.

Walk-By Demonstrations

A walk-by demonstration is one in which large numbers of demonstrators walk past the White House at varying rates of speed and at varying levels of concentration. The demonstrators might assemble at some convenient location near the White House, such as Lafayette Park or the grounds surrounding the Washington Monument, and then proceed toward one end of the White House sidewalk where they would walk along its entire length and either disperse or repeat the cycle. The numbers of persons such a demonstration could accommodate are most conveniently expressed in terms of total numbers of demonstrators per hour.

TABLE 10

NUMBER OF STANDING DEMONSTRATORS ACCOMMODATED WITH VARYING AMOUNTS OF SIDEWALK AT VARYING DEGREES OF CONCENTRATION

Number of Square Feet per Demonstrator	Square Feet of Sidewalk Space			
	18,250	20,075	21,900	25,550
2.5	7,300	8,030	8,760	10,220
3.5	5,214	5,736	6,257	7,300
4.5	4,056	4,461	4,867	5,678

In Tables 7 and 8 it was shown that at least the following numbers of ordinary pedestrians could walk across each foot of sidewalk width at varying speeds and concentrations per minute: 27 walking at 4.0 fps, 26 walking at 3.0 fps, 22 walking at 2.0 fps, and 12 walking at 1.0 fps. The numbers of demonstrators that can walk by the White House per hour per foot of sidewalk width are equally large and are simply expressed by multiplying the numbers of pedestrians, stated earlier, by the width of sidewalk feet available and the number 60 to obtain the results in terms of total demonstrators per hour. These results are given in Table 11.

TABLE 11

NUMBER OF WALK-BY DEMONSTRATORS THAT VARYING SIDEWALK WIDTHS COULD ACCOMMODATE PER HOUR AT VARYING SPEEDS

Rate (fps)	Available Sidewalk Width (ft)			
	25	27.5	30	35
4.0	40,500	44,550	48,600	56,700
3.0	39,000	42,900	46,800	54,600
2.0	33,000	36,300	39,600	46,200
1.0	18,000	19,800	21,600	25,200

SUMMARY AND CONCLUSIONS

The dimensions of the sidewalk in front of the White House are approximately 775 ft by 37.5 ft. The sidewalk area available for pedestrians and demonstrators is approximately 730 ft by 35 ft and encompasses a total area of 25,550 sq ft.

A study was undertaken to determine, first, how much sidewalk space was required by the maximum number of pedestrians that now, or in the future, are likely to use the White House sidewalk, and, second, how many orderly demonstrators can reasonably be accommodated in the remaining sidewalk space. Based on actual pedestrian counts conducted at the White House sidewalk and on other relevant traffic engineering studies, it was determined that the maximum projected number of pedestrians that might use the sidewalk during the peak summer periods was 3,260 per hour. It was then determined that 3,260 pedestrians per hour could be accommodated within a traffic lane 5 ft in width in which the pedestrians could group themselves into concentration of 0.0 pedestrian per sq ft, or 1 pedestrian every 20 sq ft.

The remaining sidewalk space was then studied to determine how many circulating, stationary, and walk-by demonstrators could reasonably be accommodated in that space at varying degrees of concentration. It was found that when demonstrators circulated at the rate of 1.0 fps and at a concentration of 0.2 demonstrator per sq ft, the entire 35 ft of sidewalk width could accommodate 5,110 demonstrators, 30 ft of sidewalk width could accommodate 4,380, and 25 ft of sidewalk width could accommodate 3,650.

The number of stationary demonstrators that could stand in various amounts of sidewalk space was even larger. At the optimum concentration of 2.5 sq ft for every demonstrator, 10,220 demonstrators could occupy the entire 35 ft of sidewalk width, 8,760 could occupy 30 ft of sidewalk width, 8,030 could occupy 27.5 ft of sidewalk width, and 7,300 could occupy 25 ft of sidewalk width.

Finally, the number of demonstrators that could walk by the White House at various rates of speed over various widths of sidewalk space was determined. At between 3.7 and 4.3 fps, 56,700 demonstrators per hour could pass by the White House over 35 feet of sidewalk width, 48,600 could pass over 30 ft of sidewalk width, 44,550 could pass over 27.5 ft, and 40,500 could pass over 25 ft.

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PEDESTRIAN EFFECT ON AT-GRADE INTERSECTION VEHICULAR FLOW

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The basic objective of this study was to identify variables that are significant to the pedestrian effect on vehicle flow through at-grade intersections. Data were collected and analyzed to determine if a statistical relationship existed between the selected variables and the vehicle-seconds of delay being caused by pedestrian-vehicle frictions as a result of both vehicular and pedestrian movements at the study intersections. The multiple-regression analysis of the data produced three regression models that should give accurate estimates of the vehicle-seconds of delay. The first model included the data for all 6 study intersections, 3 with all one-way streets intersecting and 3 with 1 one-way street and 1 two-way street connecting. The second model was applied to 3 intersections with one-way streets intersecting. The third model was derived from the data on 3 intersections with 2 one-way street legs and 2 two-way street legs. A definite statistical relationship was found to explain the pedestrian effects on vehicle delay at typical urban intersections.

•URBAN traffic engineers have been dealing with the problems of safe, efficient pedestrian movements for a long time, but the possible effect of pedestrian movement on vehicular flow through at-grade intersections has had relatively little attention, and the attempts to use various concepts of the three E's approach (engineering, enforcement, and education) have not met with a very high degree of success. However, many engineering ideas that have been applied to pedestrian safety problems for intersections may also be used to accomplish smooth, coordinated pedestrian and vehicular flow.

The complex system of pedestrian-vehicle movement at intersections consists of four elements: the vehicle, the road, the driver, and the pedestrian. Various factors such as increasing vehicle registration and numbers of pedestrians, high-speed vehicles, and the right-of-way conflict between drivers and pedestrians are adding to the complexity of the system. The problems generated by this increased complexity have not always received a satisfactory solution through application of conventional systems of approach. In fact, pedestrians are equally as responsible as drivers for highway safety and smooth, efficient operations, and they should be held equally liable for accidents and smooth traffic flow.

A very large majority of urban intersections are still at-grade crossings and must be considered in any study of the pedestrian effect on intersection vehicle flow. One method that may be considered as a solution to many problems of pedestrian-vehicle friction is the "scatter" pedestrian phase in the signal cycle. This approach, however, has a disadvantage because a uniform reduction in available green time for vehicle traffic is experienced regardless of the pedestrian volume through the intersection. Another possibility is the grade separation of vehicles and pedestrians at intersections; this approach has been recognized as the ideal solution to reduce interference between

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pedestrians and vehicle flow. However, the capital investment as well as the physical restrictions involved limit the use of this type of system. Therefore, pedestrian tunnels and overpasses have been used only at locations of very high pedestrian and vehicular volumes, such as schools, factories, sports arenas, and freeway locations.

The primary consideration for the pedestrian at intersections is safety, but the possible effect of pedestrian movement on vehicle flow should also be considered seriously. Pedestrian effect on vehicle flow has not been studied adequately in the past; in fact, this effect was not included as a factor affecting intersection capacity in the Highway Capacity Manual (8).

This study attempted to determine the effects of pedestrians on vehicular flow, in terms of vehicle delay, through at-grade intersections by identifying some of the relevant variables that may affect both the pedestrians and the vehicular flow. The variables selected are quantifiable factors for which the data are relatively easy to collect. These factors were used to form a statistical relationship among variables by multiple-regression analysis. The independent variables that most significantly affected pedestrian-vehicle friction were included in the regression models for the different types of intersection operations. From these models a reasonably accurate estimate of the actual vehicle delays due to pedestrian-vehicle friction at the selected types of intersections can be derived.

LITERATURE REVIEW

The coordinated movement of both pedestrians and vehicles through at-grade intersections has not been the subject of many studies; therefore, the number of techniques that have been used to develop a statistical relationship among relevant variables appears to be very limited. This section reviews some of the work previously done in the field of coordinated pedestrian-vehicular flow through at-grade crossings.

The factors affecting vehicular flow at an at-grade intersection are broken into four general categories (8): (a) physical and operating conditions, (b) environmental conditions, (c) traffic characteristics, and (d) control measures.

The pedestrian is a physical element of the intersection and must be given the same consideration as any other factor of the physical and operating conditions. Miller (11) states that "supervising, controlling, guiding, or planning any phase of the traffic problem means dealing with human beings, and no one is perfect. Errors occasionally do occur. Striving always to be broadminded, sincere, tolerant and to consider the other person's viewpoint and problems will promote efficiency and good relations. Valuable time will be saved, life will be more pleasant, and, most important, we shall go farther toward accomplishing our goal—the prevention of congestion, accident, injuries, and death on our streets and highways."

The pedestrian reactions at the curb must be considered along with all other environmental factors for the intersection. A study by DiPietro and King (5) showed that the number of pedestrians waiting at curbside has a significant effect on the near-side gap as well as the near-side plus far-side gap accepted by an individual pedestrian within the group. Statistically, it was also found that volume of traffic enters into the pedestrian crossing decision. Group crossing speeds were found to be slower than individual crossing speeds and groups of pedestrians accepted shorter gaps than individual pedestrians.

Some traffic characteristics of the intersection must also be given serious consideration. Wegmann (18) has shown that the acceptable gap or degree of chance that a pedestrian is willing to take is a function of (a) speed of approaching vehicles, (b) average number of waiting pedestrians, (c) average delay of waiting pedestrians, (d) sight distance of intersection, (e) characteristic of pedestrians, (f) environmental conditions, and (g) width of roadway to be crossed.

A study by Hoel (9) showed that the mean walking speed of pedestrians was approximately 4.80 fps. The mean speed for men was 4.93 fps and for women 4.63 fps. The speeds vary depending on the trip purpose, e.g., 4.92 fps for 8:00 to 9:00 a.m. work-oriented trips and 4.45 fps for 1:00 to 2:00 p.m. shopping and business purposes. The walking speed of the pedestrian has a significant effect on the exposure time or time that he is apt to cause a vehicle delay.

The control measures are probably the most important factors when considering pedestrian-vehicle friction. Generally, crosswalks should be marked in all areas to delineate clearly where pedestrians should cross the roadway (2). The marking should conform to the Manual on Uniform Traffic Control Devices (14).

A study by Welke (17) pointed out that a multiphase operation gives rise to unacceptable delays. A "share-the-green" system reduced cycle length by 50 percent over the "scatter" system. Since adjustments were made in the signal system, traffic moves freely in the study area without backing up and without racing pedestrians.

A study in Toronto by Rotman (13) showed that the use of the pedestrian crossing gave a much more efficient operation (less delay) than either pedestrian-actuated signals or a pre-timed pedestrian phase in the signal cycle. The accident records also reflected that there were fewer accidents where the pedestrian crossing was used than at signalized locations. The pedestrian crossing system used in Toronto was composed of lines on the roadway, signs over the roadway, no signal, and warning signs in advance. This operation was set up with distinctive pedestrian laws that were backed by enforcement. A comprehensive education program was conducted prior to putting this system into operation, and a public opinion poll conducted for the system showed that 88 percent of the population had favorable opinions. This was a very flexible system that utilized cooperation between pedestrians and drivers and created minimum delays.

Box and Alroth (4) showed that the separate pedestrian phase in the signal cycle, if used for minimum delay and maximum efficiency, would frequently operate only during absolute peak periods such as for employees leaving industrial plants and office buildings. In the absence of a better controller system, the "time-clock-controlled fixed-time" controller appears preferable. In most cases, pedestrian fixed-time signals of the continuously operating type should not be used. The "scatter" pedestrian phase gives a uniform vehicle delay regardless of the pedestrian volume through the intersection.

Concerning the capacity of a street network, intersections are usually capacity bottlenecks. The most common method of attempting to increase the capacity of a network has been to make a change in the signal cycle or in the widening of the arterial streets. Vuchic (16) has shown that the vehicular capacity of signalized intersections with a separate pedestrian phase increases with street width at a decreasing rate, reaches an absolute maximum around 110 ft, and then begins to decrease. Because street width is directly related to pedestrian crossing time, it is a very important factor in the vehicular capacity of at-grade intersections. Consequently, the traffic engineer must view the pedestrian at at-grade intersections as an element of the traffic stream in order to provide an optimal solution. One possible improvement for the wide-street situation is the use of pedestrian refuge islands in the center of multilane divided arterials.

ANALYSIS OF RELEVANT VARIABLES

From the review of previous studies concerning vehicular flow at signalized intersections, it was found that a model-building technique has been most successful in explaining the relationship among independent variables. For example, the CEIR multiple-regression models (19) that used some of the same data used for the Highway Capacity Manual intersection capacity factors analysis were used as a guideline in this study. Before the development of a multiple-regression model can proceed, one of the first and most important considerations is the identification of significant variables that affect pedestrian-vehicle friction.

In this study two criteria were used to select variables: those factors for intersection capacity that had been shown in previous studies to affect significantly pedestrian-vehicle friction and other variables that may have a significant effect on pedestrian-vehicle friction. The following variables were considered to have possible effects on the vehicular traffic flow where the pedestrian-vehicle conflict occurs. These variables are grouped into three categories—pedestrian, driver, and environment—as follows:

1. Pedestrian—understanding of the traffic control system; familiarity with roadway geometry; trip purpose and length; defects in sight or hearing; psychological condition and possible blood alcohol content; attitude toward vehicular traffic; and age and sex.
2. Driver—attitude toward pedestrians; psychological condition; age and sex; familiarity with pedestrian traffic regulations; defects in sight; desirable vehicle speed; and vehicle performance capability.
3. Environment—enforcement campaign; educational campaign; clarity and uniformity of traffic control systems; ambient conditions; physical layout of intersection; pedestrian and vehicle volumes; parking conditions, loading zones, and bus stops; percent of turning movements; total cycle length or maximum red interval; location within metropolitan area; and adequacy of roadway lighting.

After consideration was given to the possible variables for this problem, nine that were considered to be quantifiable and most significant to the pedestrian-vehicle friction effect on vehicular flow were selected for the final analysis. These nine variables and the reasons for their selection are as follows:

1. Number of pedestrians involved (X_1)—The greater the number of pedestrians involved in the pedestrian-vehicle friction the higher is the probability of a larger vehicle delay due to the increase in pedestrian-vehicle friction. This variable represents the number of pedestrians that actually cause delays.
2. Pedestrian violations (X_2)—The greater the number of pedestrian violations the higher is the probability of a possible vehicular delay as a result of increased exposure. For example, a pedestrian is considered to be in violation if he departs the curb on a green signal for the street that he is crossing or on a yellow signal for the connecting street.
3. Parking conditions (X_3)—Parking near the intersection could reduce exposure time by reducing the effective street width, which may reduce possible vehicle delays. This variable may be quantified by the number of sides of the legs of the intersection on which parking is permissible. Loading zones should be counted as parking areas, but corner bus stops should not be considered parking areas.
4. Vehicle volume (X_4)—Increased vehicle volume may increase the probability of a vehicle delay due to a possible increase in exposure. This value is the total vehicle volume on all legs of the intersection for a given interval.
5. Pedestrian volume (X_5)—An increase in pedestrian volume may also increase the probability of a vehicle delay due to a possible decrease in length of gap acceptance. This variable value is the total pedestrian count for all pedestrian movements through the intersection in a given interval.
6. Percentage of left turns (X_6)—The probability is high that a substantial increase in vehicle-pedestrian friction may occur with an increased percentage of left-turning movements as a result of the increase in exposure.
7. Percentage of right turns (X_7)—The same high probability of increased pedestrian-vehicle friction can occur during right-turning movements as occurs during left-turning movements.
8. Maximum red interval (X_8)—Maximum red interval was considered to be of possible importance because a longer red interval may reduce gap acceptance that could have an effect on the vehicle-pedestrian friction. The length of the cycle was found to have significant correlation in the Washington, D.C., intersection traffic flow studies (17).
9. Street width (X_9)—Street width determines the length of time or distance that is subject to pedestrian-vehicle friction. This distance was measured from curb to curb on all intersection legs.

Vehicle seconds of delay (Y), the product of the number of cars in the queue and the time that they were delayed, was used as the dependent variable for this analysis. This value can be a measure of the loss in vehicle flow through an intersection. Therefore, in this study it will cover only the vehicle delay that was caused directly by pedestrians interfering with the vehicle traffic stream.

Many other factors were also considered as being important in the determination of the pedestrian-vehicle friction effect on the vehicular flow through the intersection but were deleted from this analysis as a result of some peculiarity in the data collection procedure for the study intersections. Some of these are as follows:

1. Bus stops—Four of the six intersections had one bus stop, one intersection had two bus stops, and one of the six did not involve any bus stops.
2. Total cycle length—All six of the signals had 70-sec cycle lengths.
3. Location within metropolitan area—All intersections have central business district characteristics; therefore, no attempt was made to include an adjustment factor for location in the metropolitan area.
4. Metropolitan area population—All data were collected in the same city; therefore, the metropolitan population for all samples would be in the 500,000 population range.
5. Crosswalk marking—All sample locations except one had the crosswalk markings in place. Visual inspection of the data did not show any significant difference at the one location.
6. Types of signalization—All signal systems at the study locations were "share-the-green" systems with turning movements being permitted while the pedestrians were crossing the intersecting street.

DATA COLLECTION

After reviewing the intersection capacity section of the Highway Capacity Manual (8) and other previous work in the field of intersection vehicular flow, the decision was made to select six study intersections in Richmond, Virginia. This decision was based on the larger population of the metropolitan area, the dense vehicular traffic, the dense pedestrian movement, and the large central business district.

The primary limitations affecting the data would be relative to the metropolitan area population and the central business district of the city. Serious limitations were not imposed because Richmond has a metropolitan population of approximately 500,000 and has a relatively typical CBD. This problem is not considered serious because vehicle-pedestrian friction does not become a significant problem until the metropolitan population becomes rather large and then it should not change significantly relative to an increase in population.

Sample Intersections

Three of the six intersections selected consist of all one-way street legs. These three intersections are 8th and Marshall, 8th and Main, and 5th and Grace. Main and Grace Streets are high-volume westbound traffic arterials. Marshall carries a relatively high volume of eastbound traffic. Both 5th and 8th Streets are one-way cross streets (north-south) that carry a relatively high vehicle volume and produce a high frequency of turning movements.

The other three intersections selected are junctions of 1 one-way street and 1 two-way street. These three are the intersections of 9th and Main, 11th and Marshall, and Harrison and Franklin. A typical study intersection is shown in Figure 1. As stated previously, Marshall and Main are high-volume eastbound and westbound arterials respectively. Franklin Street is also a high-volume eastbound arterial. Harrison, 9th, and 11th are two-way cross streets (north-south) that produce a high frequency of turning movements. The fluctuations at a typical study intersection are shown in Figure 2.

Collection Procedure

The data collection phase of this study was conducted by three persons at the two locations on Marshall Street and the one location on Franklin Street. The equipment used was two 12-key counter boards; one to record the vehicular volume and turning movements and the other to record the pedestrian movements. The third person used a watch to determine the vehicle-seconds of delay caused by the pedestrian-vehicle friction.

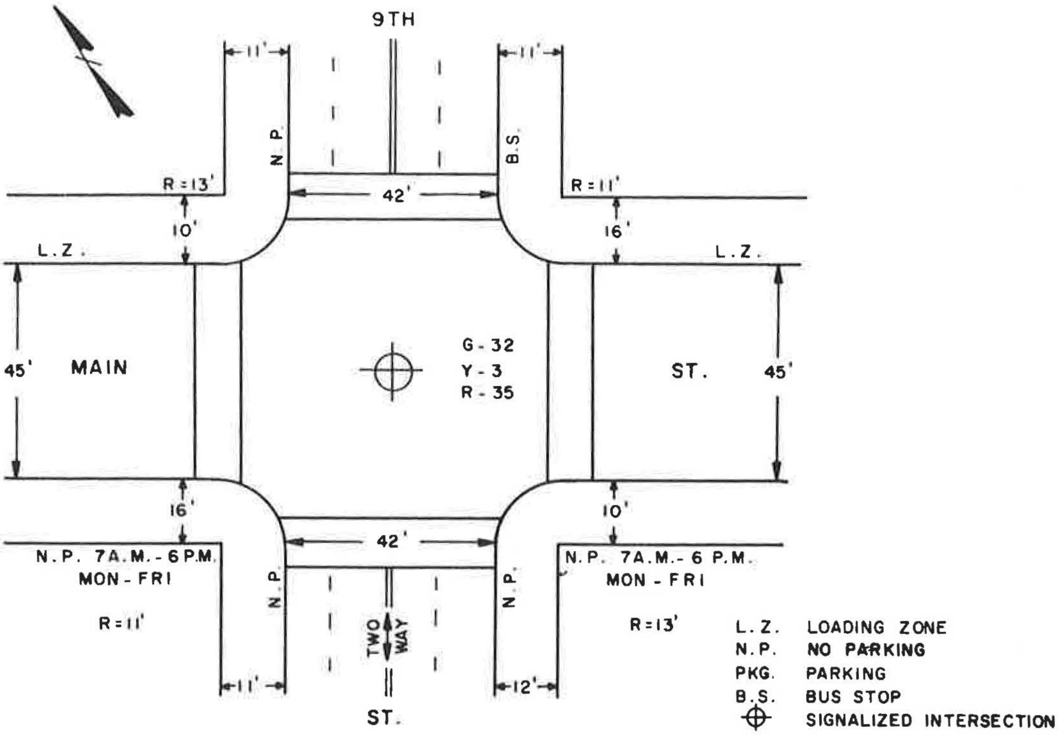

Figure 1. Typical study intersection, 9th and Main Streets.

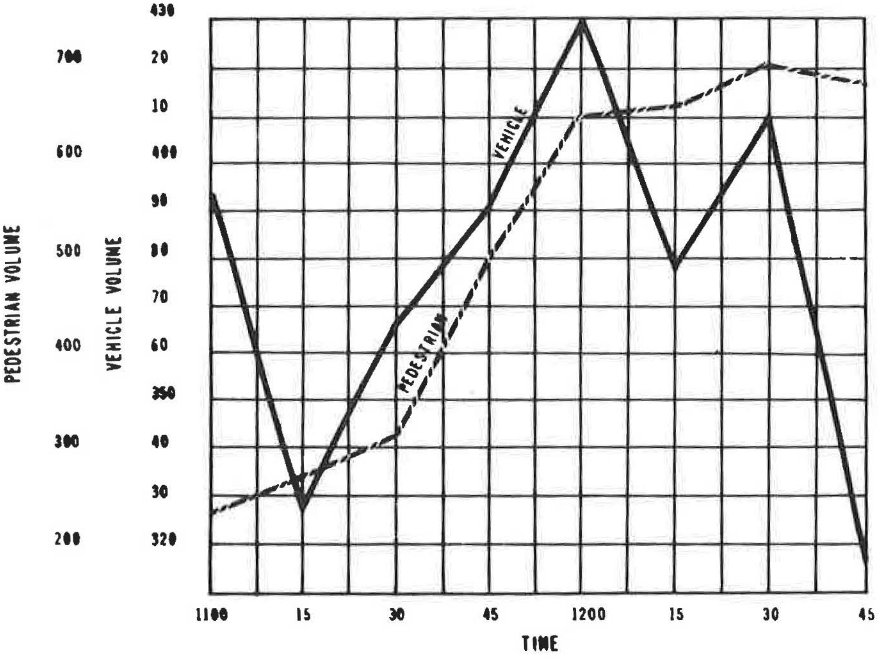

Figure 2. Vehicular and pedestrian volumes per 15-min interval, intersection of 9th and Main Streets.

In the data collection phase of the two Main Street locations and the one intersection of Grace Street an additional observer was involved because of the relatively high pedestrian volume. Three persons used 12-key counter boards, and one used a watch to determine the vehicle delays. The counter boards were used in the following manner: One was used to determine vehicular volumes and turning movements, and two were used to determine the pedestrian movements, each being used for half of the intersection by breaking the workload down to pedestrian departures from each of two street corners.

Data were collected for all variables simultaneously from 11:00 a.m. to 1:00 p.m. on Tuesday, Wednesday, and Thursday. This period was chosen because a preliminary field observation showed that pedestrian movement and vehicle traffic flow were both high during this time giving a high potential for pedestrian-vehicle conflict.

MODEL DEVELOPMENT

After the relevant variables had been identified and the data on these variables had been effectively collected, a statistical method, the multiple-regression technique, was used to formulate a relationship that would, to some extent, describe the effect of pedestrian movements on the vehicle traffic flow at the study intersections. It is hoped that the resulting relationship is meaningful both in the general case where the data from all test intersections are included and in the specific case where the data input is limited to similar types of intersection operations.

Modeling Techniques

Two regression analysis programs developed by the Health Sciences Computing Facility of the University of California (6) were used for the computer analysis.

The BMDO2R, a stepwise regression program, was first used to determine the most significant of the nine variables that were considered. This program computed a sequence of multiple linear regression equations in a stepwise manner. At each step one variable is either added or deleted from the regression equation. The variable added is the one that makes the largest reduction in the error sum of the squares and residual sum of the squares and has the highest partial correlation coefficient with the dependent variable partialed on the included variables, and the variable that if added would have the highest F value. Variables are automatically removed if their F values become too low.

The criteria used in this analysis were an F-level of significance of 0.10 for an independent variable to enter the model and an F-level of significance of 0.05 for any independent variable in the model to remain.

After the stepwise regression program was used to determine the independent variables to be included in the model, BMDO3R, a multiple regression with case combinations program in which the variables in the model must be specified, was then used to analyze the data again. This program gives the correlation coefficients for all of the variables in the model and a table of residuals for the dependent variable in the model.

Model Formulation

Three models were developed in this study. Model 1 used the data from all six intersections. Model 2 was derived from the data of the three intersections with all one-way operations. Model 3 was applied to the intersections of one-way with two-way streets. The resulting models from this analysis are as follows:

$$Y = -87.10 + 2.48\,X_1 + 0.25\,X_4 - 0.05\,X_5 + 2.67\,X_7 \qquad (1)$$

$$(R = 0.941,\ E_S = 37.40)$$

$$Y = -3715.58 + 2.63\,X_1 - 0.28\,X_4 - 0.19\,X_5 + 12.70\,X_6 + 90.49\,X_9 \qquad (2)$$

$$(R = 0.931,\ E_S = 34.65)$$

$$Y = -164.65 + 2.19 X_1 + 0.30 X_4 + 1.78 X_6 + 5.46 X_7 \quad (3)$$

$$(R = 0.961, \; E_S = 37.47)$$

The procedures of the stepwise regression analysis for developing the models are given in the Appendix.

The multiple correlation coefficient (R) indicates the degree of association between the independent variables and the dependent variable in the model. The higher the value of R, the greater is the reliability of the association.

The standard error of estimate (E_S) indicates the degree of variation of the data about the regression line. This is a measure of the error to be expected in predicting the dependent variable from the independent variables in the model.

Model Evaluation

In the evaluation of a statistical model developed by multiple-regression analysis, one of the more important considerations is the relationship between the dependent variable and the independent variables in the model. The variables X_1, pedestrians involved, and X_4, vehicle volume, appear in all three models. The number of pedestrians involved in the delay resulting from pedestrian-vehicle friction is obviously an important factor in the vehicle delay value. The greater the number of pedestrians involved, the greater is the delay time. The vehicle volume through the intersection will also have a significant effect on the vehicle delay time because the greater the vehicle volume, the greater is the exposure rate or probability of a delay.

The percentage of left turns, X_6, is also significant in determination of the vehicle delay time. Past studies have shown that turning movements increase the pedestrian-vehicle friction, which contributes to the delay time to be expected. This variable could have appeared in all three models but was not included in the combined type of intersection model because it did not give a significant enough increase in the R value to justify its inclusion. Also, four independent variables appeared to give a sufficiently stable model.

Average street width, X_9, appears in both models for the specific type of intersection. This can be expected because an increase in street width increases the exposure time or probability of friction between vehicle and pedestrian traffic.

The pedestrian volume, X_5, appears in both the combined type of intersection model and the one-way-only intersection model. This again is a case where increased exposure or probability of a conflict occurs with the increased pedestrian volume. Past studies (5) have also shown that a pedestrian in a group will take a greater risk than an individual pedestrian waiting on the curb. An increase in pedestrian volume gives a greater probability that a group situation exists; however, the data for this study do not reflect group size.

The percentage of right turns, X_7, appears in both the combined type of intersection models and in the one-way-with-two-way intersection model. Again, this is a case confirmed by past studies (1) that indicate that turning movement increases the pedestrian-vehicle conflict, which increases the vehicle delay time.

Model Application

The data collection for the application of these models can utilize a much less sophisticated collection procedure than was utilized in the research without any loss of quality in the results. The vehicle volume that appears in all of the models can easily be collected with a 15-min recording counter on each leg of the intersection. The pedestrian volumes as measured by both X_1 and X_5 as well as the number of turning vehicles will still need to be counted manually.

The substitution of these data into the appropriate model would give the range of delays that was being experienced at each intersection. From a study of these delays better traffic engineering judgment can be derived. The enhanced judgment could then be used in taking the necessary correctional measures to provide for safe intersections that also yield maximum efficiency.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

This study was initiated to determine the statistical relationship between the significant independent variables presented in this study and the vehicle-seconds of delay caused by pedestrian-vehicle friction at at-grade intersections with "share-the-green" type signalization. A significant relationship was found, and the three models developed in this study are the result of the multiple-regression analysis of data on the relevant variables.

The three models developed in this study have high R values and have independent variables that have passed F-tests at 0.10 significance. Statisticians have shown that high R values do not necessarily mean a good regression model if the independent variables that are used have little or no effect on the dependent variable; it is thought that this is not the case in this study because previous studies have also identified the same significant variables.

Further research is needed in the field of vehicle delays resulting from pedestrian-vehicle friction so that better guidelines can be developed for coordinated, smooth pedestrian and vehicle movement through at-grade intersections. The following specific recommendations for further research are made:

1. Each of these three models should be field-tested under much more extensive conditions. The 48 observations at the six study intersections were considered sufficient for statistical validity, but a more extensive test may show any shortcomings in the models.
2. Serious consideration should be given to the possibility of including a pedestrian-effect factor in at-grade intersection analyses. At present this type of factor is nonexistent; as this study has shown, however, there is a definite effect resulting from pedestrian-vehicle friction.

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Appendix

STEPWISE REGRESSION ANALYSIS FOR MODELS

TABLE I

Model 1

Stepwise Regression Equations

Model	R	E_s	F
$Y = 19.15 + 2.36 X_1$	0.917	42.54	244
$Y = -40.65 + 2.16 X_1 + 0.23 X_4$	0.934	38.68	153
$Y = -26.79 + 2.42 X_1 + 0.20 X_4 - 0.05 X_5$	0.937	38.05	106
$Y = -87.10 + 2.48 X_1 + 0.25 X_4 - 0.05 X_5 + 2.67 X_7$ *	0.941	37.40	83
$Y = -160.60 + 2.19 X_1 + 0.35 X_4 - 0.03 X_5 + 2.86 X_6 + 4.17 X_7$	0.943	37.26	67

*Final Model

TABLE II

Model 2

Stepwise Regression Equations

Model	R	E_s	F
$Y = 13.40 + 2.42 X_1$	0.862	43.60	63.6
$Y = -97.85 + 1.52 X_1 + 0.52 X_4$	0.891	39.89	40.6
$Y + -161.43 + 1.39 X_1 + 0.43 X_4 + 14.52 X_6$	0.906	38.18	30.5
$Y = 120.56 + 1.88 X_1 + 0.35 X_4 - 0.06 X_5 + 12.62 X_6$	0.914	37.53	24.1
$Y = -3715.58 + 2.63 X_1 - 0.28 X_4 - 0.19 X_5 + 12.70 X_6 + 90.49 X_9$*	0.931	34.65	23.5
$Y = -4783.47 + 2.35 X_1 + 20.67 X_3 - 0.54 X_4 - 0.16 X_5 + 14.33 X_6 + 115.85 X_9$	0.935	34.78	19.6

*Final Model

TABLE III

Model 3

Stepwise Regression Equations

Model	R	E_s	F
$Y = 24.73 + 2.32\ X_1$	0.940	42.93	166.9
$Y = -36.62 + 2.23\ X_1 + 0.21\ X_4$	0.955	38.10	109.3
$Y = -119.91 + 2.32\ X_1 + 0.24\ X_4 + 4.68\ X_7$	0.960	36.81	78.9
$Y = -164.67 + 2.19\ X_1 + 0.30\ X_4 + 1.78\ X_6 + 5.46\ X_7$*	0.961	37.47	57.2
$Y = 12.81 + 2.21\ X_1 + 0.31\ X_4 + 5.00\ X_6 + 5.96\ X_7 - 5.56\ X_9$	0.963	37.52	45.8

*Final Model

PEDESTRIAN TRAVEL DEMAND

Boris Pushkarev and Jeffrey M. Zupan, Regional Plan Association, New York

The design of central business districts, where a substantial portion of the 1 billion sq ft of office floor space built in the nation during 1960-1970 has been located, will become increasingly important in the future. Yet, traditional transportation planning studies, including origin-destination home interviews, fail to account adequately for non-home-based, especially pedestrian, travel within the CBD. Pedestrian facilities are seldom dimensioned in proportion to the trip generation of the buildings they serve. As a result, pedestrian congestion in large central business districts is quite common. This study, focused on midtown Manhattan, first relates pedestrian density to walkway space and building floor space at two points in time. Available walkway space and building floor space in retail, restaurant, and office use are found to affect significantly the presence of pedestrians. Estimating equations are presented and evaluated. The daily cyclical variation and directional distribution of pedestrian travel at buildings with different uses and at selected street locations are given. Relationships to daily trip generation rates and the relative magnitude of design period flow are suggested. Trip length characteristics are shown for the walking portion of various trips at the CBD end and are analyzed by purpose and by mode. The average walk is found to be about ⅓ of a mile, and walk-only trips are found to compose about 26 percent of total CBD trip ends. Although Manhattan represents a limiting condition with regard to trip-end density and trip length, the factors derived represent a useful input into the development of design standards for pedestrian movement.

•THE amount of travel to any place depends on the attractiveness of the destination and its accessibility (1). In an urban situation, the amount and type of building floor space can be used as a basic measure of travel attractiveness because other features, such as the natural qualities of a site, usually play a minor role.

Accessibility is a more complex phenomenon that can be considered to have at least three dimensions. The first is the amount and type of transportation facilities traversing the place in question. The second is people's propensity to travel along these facilities—the rate at which their trips are attenuated with distance. The third is a description of the geographic distribution of opportunities for making trips around the destination, i.e., how much and what type of building floor space is located how far away from the transportation system being considered.

The first dimension is easily quantified; in the case of motor vehicles, it can be measured by the square feet of pavement provided. Thus, if two places have an equal amount of building floor space, the one that has more square feet of vehicular pavement will also attract more vehicular trips (2). In the case of pedestrians, we may measure it by the walkway area provided.

Knowledge of the second dimension—the travel propensity—is necessary for determining at what rate to discount travel opportunities with distance. In the case of pedestrian travel, 1 million sq ft of building floor space located in the next block will certainly have a great effect on pedestrian travel at a given site, whereas 1 million sq ft located several miles away will have no effect at all. In fact, as will be shown later in this

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study, half of all pedestrian trips are less than about 1,000 ft. Thus, we do not have to be concerned with large areas when calculating a weighted average distance to all possible opportunities for walking trips.

It can be a cumbersome operation to measure the distances from each site to every other site and to weight them by the amount and type of floor space at each site, with the attenuation of trips over distance taken into account. Experience indicates that the dimension of accessibility that deals with opportunities for trips surrounding an area under investigation can be disregarded if abrupt changes in land use do not occur within an area and if great precision is not required. The reason this shortcut method can work is that, in theory, attractiveness and acessibility tend toward an equilibrium; big buildings will be erected in a place if there are enough people nearby to fill them. The dimension of accessibility that deals with the proximity of other floor space to the floor space on the site in question is thus largely inherent in the measure of the latter. Therefore, to begin our investigation, we shall study (a) building floor space by type and (b) walkway surface in a selected area to determine how they relate to pedestrian movement.

The area selected for study is in midtown Manhattan, between 40th and 60th Streets, from Second to Eighth Avenues. Practical problems of pedestrian circulation in this area are acute and urgently require solution. Analytically, the area offers a large sample of pedestrian movement at a reasonable cost. No claim is made that the rates of pedestrian travel determined for this area are universally valid. Varying densities of building occupancy, varying trip lengths, and varying social habits will no doubt result in different values for different urban places. The range of variation can only be determined by more measurements at more locations. However, the methodology used here can have a wide application, and in the absence of other data the figures derived can provide useful benchmarks.

PEDESTRIANS RELATED TO BUILDINGS AND WALKWAYS

Pedestrians visible on the surface of midtown Manhattan were counted twice: during midday and during the evening rush hour. At an instant after 1:30 p.m., a total of 37,510 pedestrians could be seen in the 1.2 sq miles of midtown; 33,280 were on sidewalks, 1,680 in streets, 1,620 in plazas, 690 in parks, and 240 in other places such as yards, roofs, and construction sites. During the evening period the total was somewhat lower. The midday and evening instantaneous counts, translated into hourly flow rates, are shown in Figures 1 and 2. The counts were based on aerial photographs obtained by a Port of New York Authority helicopter and excluded people walking through covered passageways or otherwise concealed from view. The midday photographs were taken on several weekdays between April 29 and May 21, 1969, at times ranging from 1:28 to 1:59 p.m. The evening photographs were taken between May 1 and June 4 between 5:02 and 5:30 p.m. The technique proved highly successful except in the case of some evening shots, which could not be interpreted due to deep shadows; as a result, only a two-thirds sample of the evening counts was used.

The counts were tabulated by block sectors that matched an inventory of floor space and surface use. This made it possible to related statistically, by means of multiple correlation, pedestrians to building floor space and walkway space at two points in time and at some 600 block sectors. In this case, the number of pedestrians visible on any block sector was the dependent variable, or the variable to be explained, while the walkway area and the floor space in each of 10 building-use categories (office, retail, institutional, garage, manufacturing, restaurant, theater, hotel, private residence, and others) were assumed to be the independent variables, i. e., the factors that we expect would explain the variation in pedestrian travel.

Early in the analysis it became apparent that, of the ten building uses inventoried, only office, retail, and restaurant floor space appeared to be significantly associated with the presence of pedestrians. Even when treated together, rather than individually, the seven other building uses could not contribute to a more precise explanation of the dependent variable because of their relatively low trip generation rates. Only office, retail, and restaurant use, plus the walkway area available for pedestrian circulation, were retained as significant variables affecting the presence of pedestrians on a block sector in midday. For the evening, an added factor seemed important, namely the prox-

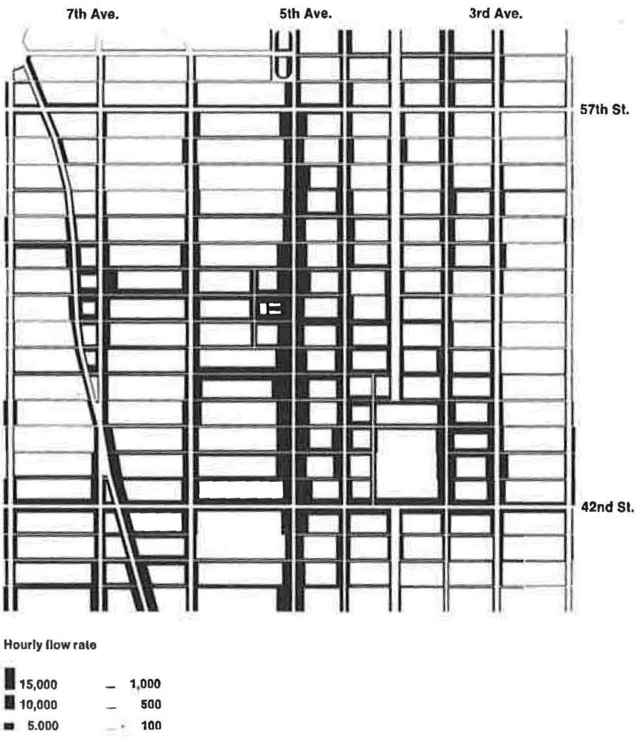

Figure 1. Mid-Manhattan pedestrian flow (12:30-1:30 p.m.).

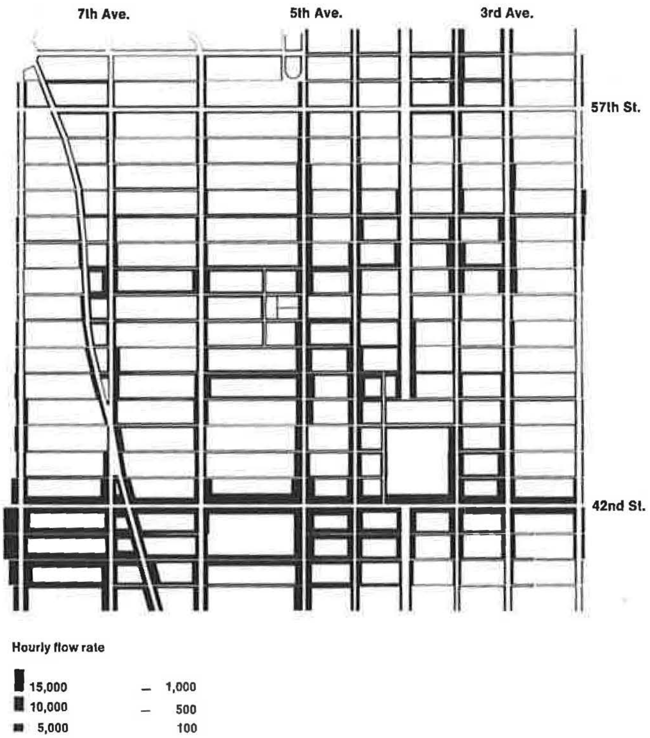

Figure 2. Mid-Manhattan pedestrian flow (5:00-5:30 p.m.).

imity of transit facilities, such as subway stops. After different measures of proximity were tested, certain functions of the distance to the nearest transit entrance proved best and were accepted as independent variables.

Another refinement that proved necessary was the differentiation between streets and avenues. Using the same equation for both tended to overestimate pedestrians in streets and underestimate pedestrians on avenues. The reason for this difference lies in the unique geometry of the Manhattan street grid. For every 5,600 ft of city width, there are about 300 lineal ft of sidewalk width on the north-south avenues and about 600 ft on the east-west streets. On the assumption that pedestrians have an equal desire to walk in a north-south direction as they do east-west, the street sidewalks should have about half the pedestrian density as the avenue sidewalks. This relationship was borne out by the helicopter counts, which found about 53 percent of the pedestrians walking north-south, and about 47 percent walking east-west, with the latter having more than twice as much room to themselves as the former.

The final result of the multiple-correlation analysis is four equations for estimating the number of pedestrians on any block or block sector at an instant after 1:30 p.m. and after 5:00 p.m., on an avenue and on a street; these are given in Table 1. The simple relationship of the avenues having about twice the pedestrian density of streets is not directly apparent from the equations because of the different incidence of building uses and the definition of block sectors, but the general tendency is for the avenue equations to produce higher values.

Intuitively, the equations in Table 1 make good sense. For example, Eqs. 1 and 2 tell us that at midday the number of pedestrians on a block sector depends on the amount of office, retail, and restaurant space—building uses that obviously attract pedestrian trips during lunchtime—as well as on the amount of surface available for pedestrians to walk on. We can also infer that retail uses attract 2 to 7 times the pedestrian trips as offices do, per unit of floor space, and that restaurants attract 13 to 25 times the trips that offices do during the noon hours. Comparing the avenue with the street equation, we see that equal increases in pedestrian space produce about equal increases in pedestrians and that the same is true of office floor space. However, retail uses on avenues attract about three times as many pedestrians as retail uses on streets, a finding that helps to explain why ground floor rents on avenues are much higher than those on streets. The main indication of the more intensive use of the avenues is the constant term at the end of the equations, which seems to indicate that, even if there is not a sidewalk or a building, there still will be 26 pedestrians per block on an avenue, whereas this is not the case on a street.

TABLE 1

EQUATIONS RELATING THE PRESENCE OF PEDESTRIANS TO BUILDING USE AND WALKWAY SPACE

Avenues, midday

$$P = 2.97 \text{ walkway} + 0.05 \text{ office} + 0.35 \text{ retail} + 1.22 \text{ restaurant} + 26.66 \qquad (1)$$

Streets, midday

$$P = 3.12 \text{ walkway} + 0.06 \text{ office} + 0.12 \text{ retail} + 0.74 \text{ restaurant} - 4.01 \qquad (2)$$

Avenues, evening

$$P = 0.06 \text{ office} + 0.20 \text{ retail} - 1.98 D + 56.70 \qquad (3)$$

Streets, evening

$$P = 3.17 \text{ walkway} + 0.04 \text{ office} + \frac{46.12}{D^3} + 2.17 \qquad (4)$$

Symbols

P = number of pedestrians at an instant in time on the sidewalks and plazas in the vehicular roadway of a block sector.
Walkway = sidewalk and plaza space on the block sector, in thousands of square feet.
Office, retail, and restaurant = gross office, retail, and restaurant floor space respectively in the block sector, in thousands of square feet.
D = distance from the centroid of the sidewalk and plaza space to the nearest transit entrance, in hundreds of feet.

Equations 3 and 4 also include office space. Because most pedestrians during the evening rush hour are leaving office buildings, this is quite plausible. Retail floor space is significant on the avenues but substantially less attractive than during midday because fewer people are shopping. Retail space on streets ceases to be significant. Pedestrian space on streets is just as important as it is during midday, but this space ceases to be statistically significant on the avenues. This anomaly can be interpreted to mean that during the more leisurely lunch hour pedestrians probably will seek out areas with more elbow-room, and distribute themselves in relation to the available sidewalk space, whereas during the evening peak they tend to rush along the avenues regardless of available space. Restaurant space ceases to be statistically significant during the evening rush hour and does not appear in either the avenue or the street equation. However, a new factor—the distance to the nearest transit entrance—emerges in the evening equations.

The distance to transit entrances must be considered in conjunction with the constants at the end of the equation. At 100 ft from a transit entrance, the avenue equation produces, on the average, -2.0 + 56.7 = 54.7 pedestrians, in addition to those generated by office and retail uses. There is a constant drop-off of about 2 pedestrians for every additional 100 ft of distance from the transit entrance. Quite a different pattern prevails on streets. At a distance of 100 ft a transit entrance produces 46.1 + 2.2 = 48.2 pedestrians on the sidewalk of a street; however, this concentration drops off very rapidly, inversely to the cube of the distance, and becomes about 2.5 pedestrians at 500 ft. Therefore, transit entrances do not strongly affect volumes on street sidewalks beyond a 500-ft radius. As can be seen from the evening pedestrian flows shown in Figure 2, the street blocks leading to transit facilities are indeed much busier than other streets, whereas the flow on avenues stretches out in a more uniform pattern.

Even though the relationships given in Table 1 appear intuitively plausible, the significance of the equations has to be evaluated by more rigorous, statistical measures. The most common such measure is the multiple-correlation coefficient, R. The correlation coefficient squared represents the fraction or the percentage of the variation that is explained. These R^2 values for the four equations are given in the first column in Table 2; the street equations explain 52 to 61 percent of the variation in the presence

TABLE 2

STATISTICAL MEASURES OF EQUATIONS IN TABLE 1

Equation	Variable	Coefficient (not rounded)	Standard Error of Coefficient	t-Value
Avenues, midday				
$R^2 = 0.36$	Walkway	2.97	0.439	6.8
$N = 344$	Office	0.0485	0.0089	5.5
$S_e = 43.5$	Retail	0.35	0.061	5.7
	Restaurant	1.22	0.370	3.3
Streets, midday				
$R^2 = 0.61$	Walkway	3.12	0.430	7.3
$N = 261$	Office	0.0575	0.0076	7.6
$S_e = 31.6$	Retail	0.12	0.039	3.1
	Restaurant	0.74	0.277	2.7
Avenues, evening				
$R^2 = 0.23$	Office	0.0622	0.0086	7.2
$N = 228$	Retail	0.20	0.062	3.3
$S_e = 39.0$	D	-1.978	0.6212	3.2
Streets, evening				
$R^2 = 0.52$	Walkway	3.17	0.567	5.5
$N = 179$	Office	0.0388	0.0102	3.8
$S_e = 34.6$	$1/D^3$	46.121	9.9240	4.6

Symbols

R = Multiple-correlation coefficient.
N = Number of observations (block sectors).
S_e = Standard error.

of pedestrians, and the avenue equations 23 to 36 percent. In both cases, the midday equations explain more of the variation than the evening ones. An interpretation of this pattern is in order.

It must be emphasized that the values any correlation equation produces are averages and not actual observations. The spread of the actual observations around the average is measured by the standard error S_e, indicated in column 1 of Table 2. The probability is about 68 percent that the actual value lies within plus or minus one standard error and about 95 percent that it lies within two standard errors of the average produced by the equation.

A major reason for the wide spread of observed values around the calculated average in our case is that the observed values are based on instantaneous photographs. There is a considerable variation in pedestrian flow from instant to instant because of the phenomenon of platooning or bunching, which is caused, to a large extent, by changes in traffic lights and affects avenues more than the longer street blocks. This is one reason for the greater accuracy of the street equations.

The extent to which the standard error is affected by platooning is best illustrated by a numerical example. Let us assume that a block sector facing an avenue has 10,000 sq ft of walkway, 1 million sq ft of office space (comparable to the Marine Midland Building in lower Manhattan), and 10,000 sq ft each of retail and restaurant use. Inserting these values into Eq. 1, we see that the block sector should have, on the average, 122 pedestrians at a midday instant. However, the standard error of Eq. 1 from Table 2 is 43.5. After multiplying that by 2, and adding it to or subtracting it from 122, we can say with a 95 percent confidence that the actual number of pedestrians on the block will be somewhere between 35 and 209. This appears to be a large spread; the high value is 1.7 times the average value. However, if one looks at manual counts of the minute-to-minute variation in pedestrian flows of a comparable magnitude during any 15-min period, one can see that the highest minute is easily 1.2 to 1.5 times the average minute. Although the evidence is indirect—helicopter counts of a block sector at 1-min intervals were not available—it seems reasonable to suggest that perhaps one-third to one-half of the standard error may be due to the short-term pulses. Fortunately, for purposes of establishing design standards, we are not so much interested in the number of pedestrians on a block at a particular instant as we are in the general magnitude of the load that can be expected. The equations provide this, even though their standard errors, as given in Table 2, appear large.

Of course, there are other sources of error than the short-term fluctuations due to platooning. For the evening equations, which generally perform more poorly than the midday ones, a major source is the large-scale pattern of pedestrian flow toward the major terminals, such as Grand Central and the Port Authority bus terminal, evident in Figure 2. The factor of proximity to the nearest transit entrance alone cannot take care of that because transit stations vary widely in the volumes they attract. During the evening peak hour 50,000 passengers enter the Grand Central subway station, whereas only 3,000 enter the Seventh Avenue stop at 53rd Street.

A related factor, operative both at midday and in the evening, is the overflow from adjacent blocks. Although we stated at the outset that, under some conditions, it may not be essential to consider the influence of neighboring areas on an area in question, the accuracy of the estimating equations would have been improved if a measure of this aspect of accessibility had been added. Thus, pedestrian flow on the block that contains St. Patrick's Cathedral is affected by the presence of 400,000 sq ft of retail floor space across the street (Saks Fifth Avenue). Similarly, of two blocks having identical-size office buildings on Third Avenue, the one closer to Grand Central has higher pedestrian flow. The overflow phenomenon, most pronounced on avenues, is only partially handled by the constant term at the end of the equations; this represents ambient pedestrians present because of the high floor space density in the area.

Next, one should mention some purely idiosyncratic factors that could not possibly be accounted for by the equations. The number of pedestrians window-shopping in the diamond district on 47th Street is substantially underestimated, as is the number of those loitering in front of peep-shows on 42nd Street between Seventh and Eighth Avenues. People congregating in front of the Public Library are also underestimated.

25. The average walking distance for all groups is 1,720 ft but varies from a low of 1,200 ft for females over 50 to a high of 2,000 ft for males 25 to 50. In and of itself, the average walking distance column in Table 7 offers few surprises: most men walk farther than women, and, generally, younger people walk farther than older people.

TABLE 7

WALKING DISTANCE BY AGE AND SEX AT TWO OFFICE BUILDINGS

Group	Percentage of Trips	Average Walking Distance (ft)	Estimated Average Net Walking Time (min)
Males, under 25	10.2	1,502	4.70
Males, 25-50	35.1	2,044	6.83
Males, over 50	6.5	1,711	6.50
Females, under 25	28.8	1,608	5.80
Females, 25-50	14.6	1,443	5.47
Females, over 50	4.8	1,244	5.59
All males	51.8	1,900	6.37
All females	48.2	1,520	5.67
Total (16,740 trips)	100.0	1,720	6.03

Turning to the characteristics of the trips themselves, we shall focus on trip purpose and mode of travel as factors affecting walking distance. Trip purpose, as is commonly known, varies widely in the course of a day. During the morning peak in a central business district, virtually all travel consists of journeys to work. In midmorning, business calls and deliveries become important. At midday, eating, shopping, and business trips predominate. In the early afternoon, trips to home become significant and increase to an overwhelming proportion of all travel during the evening rush.

The sampling procedure used at the two office buildings where interviews took place did not make it possible to draw a statistically accurate profile of trip purposes by time of day or a summary for the entire day. However, the general impression gained is that between 50 and 60 percent of the total trips in and out of the office buildings are either coming from home or going home. The rest are non-home-based and represent the kind of swirling activity for which an urban center is built. This is in marked contrast to vehicular travel in the region as a whole, which is something like 90 percent home-based.

Of the trips that are predominantly non-home-based, eating trips are most numerous (amounting to perhaps one-third at the two office buildings studied) and are followed by business calls, shopping trips, pleasure trips, and deliveries. The high rate of business calls uncovered suggests that there is indeed intensive face-to-face communication going on between office buildings, which is presumed to be one of the major reasons why they cluster in an office center. It is also interesting that the number of pleasure trips seems to rival that of shopping trips.

The trip purposes referred to represent those at the end of a journey; they take no account of intermediate stops along the way that appear to be significant in a central business district. A question asked to ascertain the number of these multi-purpose trips received poor response (more than a third of those asked did not answer); of those who did answer, about 16 percent indicated stopping for one intermediate purpose, and another 4 percent indicated for two or more purposes. Presumably, these multi-purpose trips do not include trips with such short stops as picking up a newspaper or window-shopping.

As for the mode of travel, close to 26 percent of all trips intercepted at the two office buildings are exclusively walking trips; this compares well with other studies (3). For the rest, walking represents but the initial or final link in a journey by one or several types of vehicles. As one would expect, the interviews revealed that the most walking-oriented trip purpose is eating (about 87 percent of trips to eat are walk-only trips); shopping follows (72 percent walk only); and business calls and pleasure trips come next (50 to 55 percent walk only). With regard to walking to work, it is known from the 1960 census that between 3 and 4 percent of the initial trips to work in the Manhattan central business district are made on foot; the interviews registered a much higher percentage because of return trips from eating, shopping, and other pursuits.

Table 8 and Figure 6 present the cumulative distribution of walking distances for all trips at the two office buildings studied and single out five specific trip purposes. Table 8 further shows the average and the median for all trips, and for the five trip purposes. It is evident that 50 percent of the pedestrians interviewed at the two office buildings walk less than 1,070 ft, equivalent to about four north-south blocks in Manhattan. About

TABLE 6

EXAMPLES OF DIRECTIONAL DISTRIBUTION OF PEDESTRIAN TRAVEL

Location	Percentage of Flow in the Predominant Direction		
	8:45-9:00 a.m.	12:45-1:00 p.m.	5:00-5:15 p.m.
Building entrances			
Office, flat peak	93	60	85
Office, sharp peak	98	54	98
Department store	–	68	60
Restaurant	–	73	88
Residence	88	55	56
Walkways			
Grand Central escalators	93	56	88
Grand Central area	82	50	70
48th Street	74	58	71
Fifth Avenue	70	51	61
42nd Street at Times Square	60	52	63

Note: Based on counts shown in Tables 3 and 5.

It is also evident from the outdoor cyclical counts that the aerial photographs, taken between 1:30 and 2:00 p. m. (solid hours in Figure 5), underestimate the true midday peak by anywhere from 5 to 25 percent. The evening peak is captured more accurately, solid bars in Figure 5), but there is a very substantial difference between the first and the second 15-min period during that time, which is one source of the unexplained variation in the evening correlation equations.

One last point related to the daily cycle concerns directional distribution. Table 6 shows that directional imbalance at the entrance to an office building can be rather extreme. Thus, during the peak 15-min period, between 93 and 98 percent of the flow at the two office buildings previously dealt with occurs in the predominant direction. Similarly, at the Grand Central escalators, 93 percent of the flow at 8:45 a. m. and 88 percent of the flow at 5:00 p. m. occur in the predominant direction. Just as peaks are more attenuated on outdoor walkways, directional distribution outside buildings usually tends to be more balanced; typically, two-thirds to three-quarters of the peak flow occurs in the predominant direction. In general, the greatest imbalances occur during the morning peak, followed by the evening peak. Midday, by contrast, is split rather evenly by direction. Also, walkways connecting office buildings to transit stations tend to have highly directional flow, whereas the movement pattern in shopping districts is more ubiquitous (Table 6).

WALKING DISTANCE RELATED TO TRIP PURPOSE AND MODE

Having ascertained the number of pedestrian trips produced by different building types and having looked at how this number varies in the course of a day, we can proceed to the second dimension of travel demand, namely trip length. Trip length, in general, is a very important dimension because the amount of space that has to be provided for a given number of trips depends on the lengths of the trips. Trip length, in this case walking distance, varies according to the characteristics of the person making the trip and of the trip itself. To determine some of these relationships for pedestrians in the midtown Manhattan study area, interviews were conducted intercepting persons entering or leaving a building or a transit station. They were asked where they walked to or from, for what purpose, and what other mode of travel, if any, they used on their trip; the interviewer also recorded their sex and apparent age group. A sample of 4,055 pedestrians was interviewed, representing a universe of 63,000 persons (the sampling rate varied, depending on location and time of day, from 2 to 50 percent).

Of most interest are the results of 1,400 interviews, which represent about 17,000 pedestrians entering or leaving two major office buildings, one at Sixth Avenue and 50th Street, the other at Park Avenue and 46th Street. Starting with the characteristics of the persons making the trips, Table 7 shows that the pedestrians intercepted at the two office buildings are predominantly either males 25 to 50 years of age or females under

The general conclusion to be drawn from the outdoor cyclical counts is that the peak 15-min flow rate seldom exceeds twice the average 15-min flow rate. However, it approaches this level sufficiently often to warrant accepting twice the average 15-min flow rate, on a 12-hour 7:30 to 7:30 basis, as the critical value for design purposes for outdoor walkway conditions similar to those in midtown Manhattan. The critical flow generally occurs either from 12:30 to 1:30 p.m. if an area is shopping oriented or from 5:00 to 5:30 if an area is office-building oriented. As can be seen from Table 5, between 14 and 18 percent of the 12-hour flow occurs during the hour of highest flow.

TABLE 5

DAILY PEAKING PATTERNS OF WALKWAYS IN FIVE SELECTED AREAS

Time	Percentage of 12-Hour Two-Way Flow During Each 15-Min Period				
	Grand Central Escalators (1 location)	Grand Central Area (4 sidewalk locations)	48th St., Second to Seventh Ave. (12 sidewalk locations)	Fifth Ave., 44th to 47th St. (4 sidewalk locations)	42nd St. Near Times Sq. (2 sidewalk locations)
7:30-7:45	0.6	0.6	0.8	0.3	0.5
7:45-8:00	1.4	0.9	0.8	0.3	0.7
8:00-8:15	2.3	1.3	1.1	0.5	1.0
8:15-8:30	3.3	1.8	1.8	0.8	1.3
8:30-8:45	4.3	2.5	2.9	1.3	1.6
8:45-9:00	4.3	3.2	3.0	1.8	1.8
9:00-9:15	3.9	2.7	2.9	1.5	1.9
9:15-9:30	3.4	1.7	1.8	1.1	1.4
9:30-9:45	1.4	1.4	1.4	1.2	1.3
9:45-10:00	1.3	1.4	1.4	1.0	1.4
10:00-10:15	1.0	1.2	0.8	1.2	1.4
10:15-10:30	1.2	1.4	1.0	1.4	1.5
10:30-10:45	1.1	1.3	0.8	1.7	1.6
10:45-11:00	1.0	1.5	1.0	1.7	1.5
11:00-11:15	0.9	1.5	0.8	1.6	1.7
11:15-11:30	1.1	1.7	1.0	2.0	1.3
11:30-11:45	1.3	2.0	1.5	2.2	1.9
11:45-12:00	1.6	2.2	2.0	2.6	2.0
12:00-12:15	2.4	3.3	2.4	3.4	2.5
12:15-12:30	2.2	3.5	3.4	3.7	2.9
12:30-12:45	2.1	4.0	4.0	4.6	2.8
12:45-1:00	2.5	4.0	3.7	4.2	3.1
1:00-1:15	2.6	4.0	3.5	4.2	3.4
1:15-1:30	2.7	3.8	3.2	4.4	3.1
1:30-1:45	3.0	3.1	2.9	4.2	2.8
1:45-2:00	2.4	2.7	2.7	4.1	2.7
2:00-2:15	1.8	2.3	2.6	3.6	2.6
2:15-2:30	1.7	2.3	2.4	2.9	2.4
2:30-2:45	1.7	2.3	2.3	2.6	2.0
2:45-3:00	1.4	2.2	2.1	2.6	2.3
3:00-3:15	1.6	2.0	1.9	2.0	2.3
3:15-3:30	1.4	1.7	1.8	1.7	2.2
3:30-3:45	1.6	1.7	1.8	1.8	2.3
3:45-4:00	1.2	1.7	1.7	1.8	2.1
4:00-4:15	1.8	1.6	1.6	1.8	2.2
4:15-4:30	1.6	1.8	1.9	2.0	2.3
4:30-4:45	2.4	2.0	2.2	2.1	2.2
4:45-5:00	4.3	2.9	2.9	2.4	2.3
5:00-5:15	4.3	3.9	5.0	3.4	2.8
5:15-5:30	4.0	3.1	3.5	2.9	3.3
5:30-5:45	3.4	2.5	3.1	2.4	3.0
5:45-6:00	3.2	1.8	2.4	1.8	2.7
6:00-6:15	2.1	1.4	2.0	1.4	2.5
6:15-6:30	1.7	1.0	1.7	1.1	2.2
6:30-6:45	1.4	1.0	1.4	0.9	2.0
6:45-7:00	1.0	0.8	1.2	0.7	1.8
7:00-7:15	0.7	0.7	1.1	0.6	1.9
7:15-7:30	0.4	0.6	0.8	0.5	1.5
12-hr percentage	100.0	100.0	100.0	100.0	100.0
12-hr total	89,700	137,600	67,780	146,800	80,660
12-hr average per sidewalk location	89,700	34,400	5,650	36,700	40,300

be called turnover rate. The turnover rate is a function of how a building is used—whether it attracts primarily employees working in it, or also outside patrons, whether the patrons' transactions are short or take a long time, to what extent the employees eat in or go out for lunch, and so on.

We can now look at cyclical variation in flow at walkways rather than at building entrances. Table 5 and Figure 5 show that the peaks at walkways are flatter than at building entrances. Varying trip lengths and varied trip destinations, as well as varied peak times at individual buildings, work together to flatten out the peak flow of pedestrians in the extensive "mixing bowl" of sidewalks, plazas, and other walkways.

The shape of the daily cycle at any walkway depends very much on the predominant building uses in the area. This can be readily seen by comparing the cyclical profiles in Figure 5 with those in Figure 3. The first profile, representing the escalators leading from Grand Central Terminal to the Pan American Building, resembles the profiles at office buildings but is more attenuated. For a total of 1 hour, the 15-min flow slightly exceeds twice the average 15-min rate.

About 1,000 ft away from Grand Central Terminal, at four sidewalk locations represented in the second profile, the work-trip peaks in the morning and evening become still more attenuated, and the midday lunch and shopping peak begins to compete with them; no 15-min period exceeds twice the average 15-min flow rate.

The third profile represents the average of 12 counts on 48th Street between Second and Seventh Avenues. It is distinguished by deep troughs in midmorning and midafternoon, indicating that the street serves primarily as a corridor for work trips and lunchtime trips and does not attract walkers in its own right. Because of the heavy concentration of offices in the areas it traverses, 48th Street displays cyclical characteristics that most resemble those of an office building in Figure 3. Among the five areas represented it has the highest peak; however, it lasts only 15 min and could easily be relieved by staggered exit times in adjacent office buildings.

The fourth profile is quite different and represents an average of four counts of Fifth Avenue between 44th and 47th Streets. This is an area dominated by retail shopping, and the shape of its daily cycle resembles very much that of the department store in Figure 3, with a heavy midday concentration. For 1¼ hours at midday the 15-min flow is at about twice the level of the average 15-min rate. However, the morning and evening work-trip peaks are still clearly visible.

The work-trip peaks are even less prominent in the fifth profile, representing two counts on 42nd Street just east of Times Square. Heavy midday flow for shopping and lunch as well as an unusual volume of travel in midafternoon and early evening—composed of tourists and and casual strollers—combine to make this profile the flattest of all. The peak 15-min period never even approaches twice the average rate and stays at slightly over 3 percent of the 12-hour total during both the midday and evening peaks.

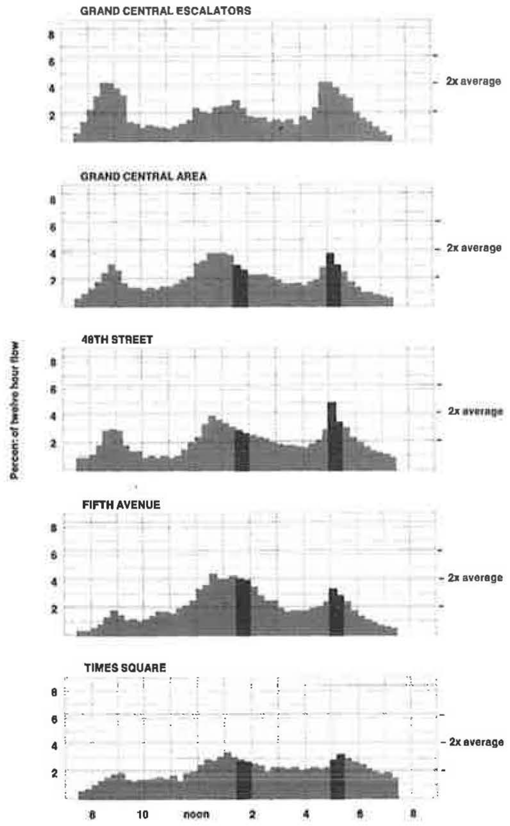

Figure 5. Two-way daily peaking patterns in walkways.

entries occur between 9:00 and 9:15 a.m., and almost 15 percent of the exits occur between 5:00 and 5:15 p.m., a factor 6 to 7 times the average—the building is predominantly a "9 to 5" operation. By contrast, the first building has a large part of its clerical work force on an 8:15 a.m. to 4:15 p.m. shift, and another part on an 8:45 a.m. to 4:45 p.m. shift, leaving less than half of its employees on a "9 to 5" schedule. The result of the staggered work hours is roughly a 30 percent reduction of the peak 15-min load, as shown in Figure 4.

In general, one should note that the cyclical patterns are not immutable laws of nature but are, to a large extent, responses to devices of social control and to ingrained conventions. For example, note the surges of people returning home "just before 6" or "just before 7" o'clock for dinner (Fig. 4, residential building).

A close look at the cyclical patterns enables us to gain some understanding of why trip generation rates vary widely between, and even within, particular categories of building use. Specifically, it enables us to calculate indoor densities of building occupancy and the number of trips in relation to the number of people occupying a building at a peak period.

The accumulation of people in a building at any particular time can be calculated by subtracting all outbound trips from all inbound trips up to that time, assuming the building was empty at first. The time and amount of the maximum accumulation can thus be determined. Dividing maximum accumulation into floor space, one can see how densely a building is occupied at the time of its peak use. As Table 4 shows, the restaurant investigated has about 36 sq ft of floor space per patron at midday, the department store about 76, and the space allocation in the three office buildings ranges from about 320 to 340 sq ft. (The average floor space allocation for all nonresidential buildings in the Manhattan central business district appears to be about 310 sq ft per person on the basis of the following: total nonresidential floor space, 570,000,000 sq ft; peak accumulation, exclusive of nonworking residents, 1,830,000 at 2:00 p.m. The allocations in the office buildings surveyed appear to be substantially higher than those commonly assumed. For example, in the mid-1960s, the gross allocation of office space per office employee in Manhattan was estimated to be only 240 sq ft.) The maximum accumulation at the apartment house—probably at about 4:00 a.m.—cannot be obtained from the difference between in and out trips because accumulation never drops to zero. However, the floor space allocation can be estimated from residential population data at about 520 sq ft.

As one would expect, the densities of building occupancy do influence trip production rates; generally, the more indoor space per peak-period occupant, the fewer daily trips per 1,000 sq ft of floor space. However, the variation in the number of daily trips per peak-period occupant appears to be greater than the variation in density of occupancy both between and within building use categories, as given in Table 4. Borrowing a term used in parking design, this number of one-way daily trips per peak period occupant can

TABLE 4

TRIP GENERATION CHARACTERISTICS OF SELECTED BUILDINGS

Building Type	Total 12-Hour Two-Way Trips	Peak Accumulation	12-Hour Trips per 1,000 Sq Ft Floor Space	Sq Ft of Floor Space Allocation at Peak Accumulation	Turnover Rate	Two-Way Peak 15-Min Trips as Percent of 12 Hours
Retail 1[a, b]	26,800	n.a.	385	n.a.	n.a.	8.4% at 12:45 p.m.
2[d]	44,540	2,330	252	76	9.6	6.2% at 12:45 p.m.
3[c]	2,140	n.a.	285	n.a.	n.a.	4.2% at 5:00 p.m.
Restaurant[a]	2,075	329	173	36	3.2	5.9% at 1:15 p.m.
Office 1[a, d]	13,690	2,980	13.06	330	2.3	7.4% at 5:00 p.m.
2[d]	23,060	4,775	14.11	340	2.4	6.9% at 8:45 a.m.
3[a, d]	5,360	980	17.06	320	2.7	5.5% at 4:45 p.m.
Residence[a, c] (290 apartments)	1,700	(520 est.) (-320 min.)	6.3	(520 est.)	1.6	3.9% at 5:45 p.m.

[a] Previously listed in Table 3.
[b] Based on a November count.
[c] Based on an April count.
[d] Based on a July count and seasonally adjusted by 1.053.

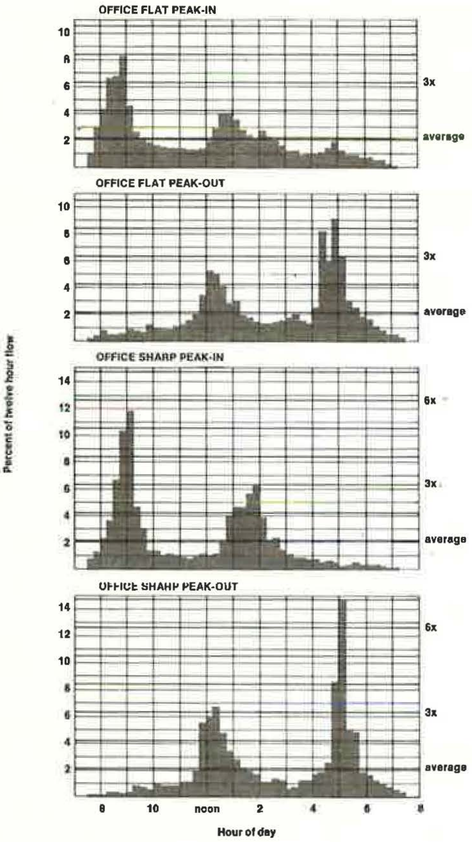

Figure 3. One-way daily peaking patterns at two office buildings.

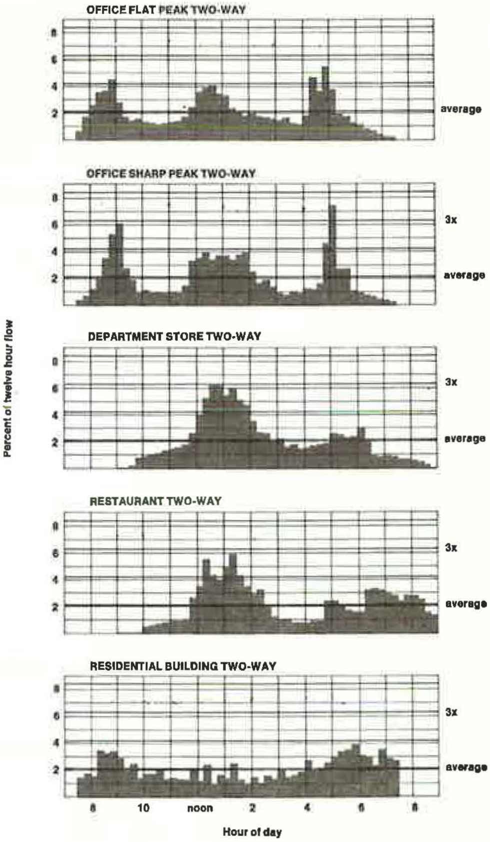

Figure 4. Two-way daily peaking patterns at five building types.

in the 3 hours after 11:45; arrivals of the "a drink after work" crowd and of the dinner patrons are clearly visible. The pattern at the apartment house is virtually the inverse of the others—some activity in the morning, a long lull with a low point around noon, and a greater amount of activity after 5:00 p. m. The irregularity of the residential graph reflects its small sample size.

A convenient way to measure the sharpness of a peak is to compare it to an average period. In our case, if pedestrian flow were even, each 15-min period would account for about 2.1 percent of the 12-hour flow. Comparing the patterns in Figure 3 on that basis, we can see that, at the second office building, two-way pedestrian flow during 15 min after 5:00 p. m. is 3.5 times the average. No other building in the figure exceeds 3 times the average flow during any 15 min. However, 2 times the average flow is exceeded quite frequently: for 45 min by each of the office buildings, for 105 min by the department store, and for 75 min by the restaurant. Only the apartment house manages to stay below that peaking level all day. The prolonged lunch peak at both office buildings approaches the level of 2 times the average. If the retail, restaurant, and residential uses shown illustrate characteristic patterns (although the detailed percentages will inevitably vary somewhat from Table 3), the question remains why the two office buildings vary so much from each other.

To answer the question, inbound and outbound pedestrian flow at these buildings is shown separately in Figure 4, based on figures in Table 3. With respect to one-way flow, peaking is even more pronounced. At the second office building, 12 percent of the begins to stir about 7:30 a.m.; reaches a peak toward 9:00 a.m., drops to a low level in the late morning; rises during lunchtime; falls in the afternoon; reaches its highest peak at 5:00 p.m.; and then gradually diminishes. Activity at the department store picks up slowly after opening, reaches a prolonged peak during the noon hours, recedes, and rises toward less than half its noontime level between 5:00 and 6:30 p.m. By referring to Table 3 we can see that this particular department store does almost 50 percent of its business during 2½ hours at lunchtime and only 6 percent during its late open hours. The pattern at the restaurant is similar. About 47 percent of the activity shown occurs

TABLE 3

DAILY PEAKING PATTERNS OF FIVE SELECTED BUILDINGS

Time	Percentage of 12-Hour Flow During Each 15-Min Period								
	Office, Flat Peak			Office, Sharp Peak			Dept. Store	Restaurant	Residential
	In	Out	Two-Way	In	Out	Two-Way	Two-Way	Two-Way	Two-Way
7:30-7:45	1.0	0.2	0.6	0.7	0.1	0.4			1.4
7:45-8:00	3.0	0.4	1.7	1.2	0.1	0.7			1.6
8:00-8:15	4.3	0.8	2.6	2.2	0.1	1.1			1.5
8:15-8:30	6.6	0.5	3.5	3.6	0.3	2.0			3.5
8:30-8:45	6.8	0.5	3.7	6.6	0.3	3.4			3.2
8:45-9:00	8.3	0.6	4.4	10.3	0.2	5.3			3.4
9:00-9:15	4.6	0.9	2.8	11.8	0.3	6.0	0.0	0.0	2.9
9:15-9:30	2.6	0.8	1.7	4.6	0.8	2.7	0.0	0.0	1.8
9:30-9:45	2.1	0.7	1.4	3.0	0.7	1.9	0.2	0.0	2.3
9:45-10:00	1.8	1.2	1.5	1.3	0.5	0.9	0.8	0.0	1.4
10:00-10:15	1.6	1.0	1.3	1.3	0.9	1.1	0.8	0.5	1.6
10:15-10:30	1.5	1.0	1.2	1.0	0.8	0.9	0.9	0.6	1.7
10:30-10:45	1.4	1.0	1.2	1.1	0.8	0.9	1.1	0.7	1.9
10:45-11:00	1.4	1.1	1.3	1.0	0.8	0.9	1.3	0.8	1.2
11:00-11:15	1.4	1.2	1.3	0.8	1.1	0.9	1.5	0.9	1.3
11:15-11:30	1.3	1.5	1.4	0.7	1.1	0.9	1.5	0.9	1.2
11:30-11:45	1.3	2.0	1.6	0.9	1.9	1.4	1.6	1.0	1.2
11:45-12:00	1.4	3.4	2.4	1.1	5.5	3.3	2.6	2.6	2.0
12:00-12:15	1.9	5.2	3.6	1.0	5.9	3.5	4.0	3.5	1.1
12:15-12:30	2.9	5.0	3.9	1.1	6.7	3.9	5.2	5.5	2.4
12:30-12:45	4.0	4.1	4.1	2.0	4.7	3.4	6.2	4.3	0.9
12:45-1:00	4.0	2.8	3.4	4.0	3.4	3.7	6.2	3.9	1.6
1:00-1:15	3.5	3.0	3.2	4.6	2.8	3.7	5.4	4.9	1.3
1:15-1:30	2.8	1.9	2.4	4.6	2.1	3.3	6.0	5.9	2.4
1:30-1:45	2.4	1.7	2.0	5.6	1.9	3.8	5.1	4.3	1.3
1:45-2:00	2.1	1.4	1.8	6.2	1.7	3.9	4.9	3.5	0.9
2:00-2:15	2.7	1.3	2.0	3.8	1.1	2.5	3.5	2.9	1.5
2:15-2:30	2.2	1.3	1.7	2.1	1.1	1.6	2.6	3.2	1.0
2:30-2:45	2.0	1.4	1.7	2.3	1.3	1.8	2.6	2.1	1.6
2:45-3:00	1.6	1.5	1.6	1.4	1.2	1.3	2.0	1.2	1.3
3:00-3:15	1.2	1.7	1.4	1.1	0.6	0.8	2.2	1.0	2.0
3:15-3:30	1.2	2.0	1.6	0.8	0.7	0.8	1.5	1.0	1.5
3:30-3:45	0.9	1.5	1.2	0.8	1.2	1.0	1.7	0.8	1.6
3:45-4:00	1.0	1.3	1.2	0.7	1.2	0.9	1.4	0.8	1.9
4:00-4:15	1.0	2.5	1.7	0.7	1.7	1.2	1.5	0.8	2.7
4:15-4:30	1.1	8.2	4.7	0.5	1.8	1.2	1.7	0.9	1.9
4:30-4:45	1.4	5.9	3.6	0.6	2.5	1.5	1.7	0.9	2.1
4:45-5:00	1.9	9.1	5.5	0.5	8.6	4.6	1.8	2.4	2.6
5:00-5:15	1.2	6.3	3.8	0.2	14.6	7.4	2.5	2.4	2.9
5:15-5:30	0.9	3.0	1.9	0.3	5.0	2.6	2.5	2.0	3.4
5:30-5:45	0.9	2.5	1.7	0.5	4.8	2.7	2.2	1.7	3.5
5:45-6:00	0.7	1.8	1.3	0.3	1.8	1.0	2.4	1.6	3.9
6:00-6:15	0.7	1.6	1.1	0.3	1.6	1.0	3.0	1.6	3.1
6:15-6:30	0.5	1.1	0.8	0.3	1.2	0.7	2.0	3.2	3.0
6:30-6:45	0.5	0.8	0.7	0.2	1.0	0.6	1.0	3.3	2.3
6:45-7:00	0.3	0.5	0.4	0.1	0.7	0.4	0.9	3.2	3.6
7:00-7:15	0.1	0.5	0.3	0.1	0.5	0.3	0.9	3.0	2.9
7:15-7:30	0.0	0.3	0.1	0.1	0.3	0.2	0.9	2.8	2.7
7:30-7:45							0.6	2.4	
7:45-8:00							0.6	2.8	
8:00-8:15							0.5	2.8	
8:15-8:30							0.4	2.5	
8:30-8:45							0.2	1.8	
8:45-9:00							0.0	1.1	
12 hours	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Sample			5,090[a]			13,000	42,300	1,970	1,700

[a] Average of 5 daily counts.

Even leaving aside these extremes, it is clear that the intensity of use varies inevitably within particular categories of buildings—no two retail stores are exactly alike and office buildings vary in their densities of occupancy and in the travel patterns they produce. Moreover, residential and other uses, which could not be registered by the statistical technique employed, also generate pedestrians. Also, both difficulties of definition and measurement errors or inaccuracies (such as the timing of the helicopter flights) contribute to the unexplained variation.

Analysis of the standard error is useful not only with regard to the equations as a whole but also in reference to particular coefficients. The coefficients of the equations in Table 1 are listed in column 3 of Table 2 (without rounding), and their respective standard errors are listed in column 4. Thus, in the case of avenues at midday, we can estimate that the addition of 1 million sq ft of office space on a block will produce 48.5 additional pedestrians, with a 95 percent confidence that the actual value will be between 30.7 and 63.3 pedestrians. Similarly, the addition of 250,000 sq ft of retail space on an avenue block sector will add 88 ± 15 pedestrians. It is evident that the standard errors of the individual coefficients are relatively much smaller than those of the equations as a whole. (The t-value, given in column 5 of Table 2, in this case represents the ratio of the coefficient to its standard error; the greater this number, the greater is the relative strength of the variable. Walkway space in all equations, retail space on avenues, and office space at midday are the variables that have the highest t-values, or the smallest standard error.)

The validity of a correlation equation can be undermined if the independent variables are related to each other. Tests revealed that, in most cases, the relationships among the five independent variables are not strong enough to affect the outcome of the analysis. For example, no significant correlation was found among the three building uses; in fact, the amount of retail and restaurant use has a slight tendency to be negatively related to the amount of office space. Proximity to transit entrances is completely unrelated to the amount of building floor space—which may be an ironic comment on past planning of midtown Manhattan. The amount of walkway space is unrelated to the floor space in retail and restaurant establishments, but it shows some positive correlation with office space, partly because of plazas in front of large new office buildings. In the evening avenue equation, that relationship is sufficiently strong (because of the particular sample of block sectors available) to justify deletion of walkway space as an independent variable.

CYCLICAL VARIATION IN PEDESTRIAN FLOW

The relationships between pedestrians and building floor space given in the correlation equations have the strength of being based on a large sample—all buildings in the study area. Their limitation is that they pertain to only two points in time. Pedestrian flow varies greatly in the course of day, and this pattern is most important for design purposes. To pinpoint the daily cycle and to verify and supplement the relationship between building floor space and pedestrian movement derived from the equations, manual counts of pedestrain flow during a 12-hour period were taken at selected locations. These include a number of typical buildings, at which all pedestrians leaving or entering in the course of a day could be observed, and several sidewalk locations. We shall turn first to the building counts.

Daily counts at five of the buildings surveyed are given in Table 3. These include two office buildings with different travel patterns, a department store, a restaurant, and an apartment house, all located in midtown Manhattan. The figures in Table 3 show the percentage of the total 12-hour flow that occurs during each 15-min interval; the totals on which these percentages are based are given for reference on the bottom line. The counts for the office buildings and the apartment house cover the period 7:30 a.m. to 7:30 p.m., those for the department store and the restaurant 9:00 a.m. to 9:00 p.m. These periods account for 100 percent of the daily traffic at the department store, almost 99 percent at the office buildings, probably close to 80 percent at the restaurant, and an estimated 70 percent at the residential building.

The figures in Table 3 are shown in Figures 3 and 4; they portray familiar patterns of pedestrian movement in a downtown business district. Activity at the office buildings

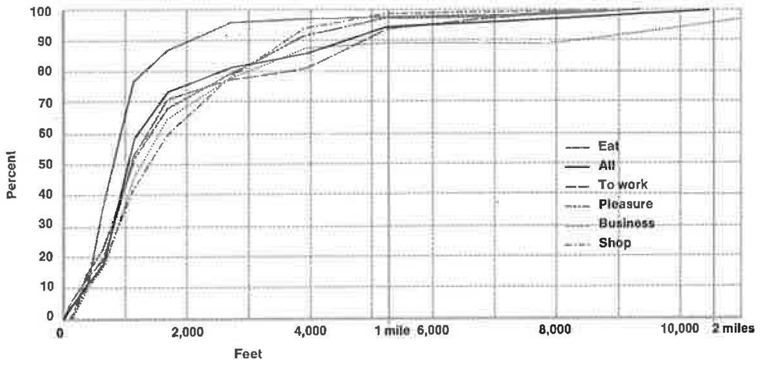

Figure 6. Cumulative walking distance distribution by purpose.

TABLE 8

CUMULATIVE WALKING DISTANCE DISTRIBUTION, BY PURPOSE OF TRIPS BY ALL MODES AT TWO OFFICE BUILDINGS

Walking Distance (ft)	Percentage of Trips Shorter Than the Indicated Distance (ft)					
	All Trips	To Eat	To Work	Pleasure	To Shop	Business
250	7	5	9	5	4	8
500	13	22	16	19	12	14
750	27	45	27	29	22	23
1,000	45	64	42	42	36	35
1,250	61	78	55	54	50	45
1,500	67	83	64	62	57	54
1,750	74	88	71	69	65	61
2,000	76	90	73	71	68	65
3,000	83	96	78	82	78	82
4,000	86	97	82	92	82	94
5,000	93	97	91	96	89	98
5,280 (1 mile)	94	98	94	98	89	98
6,000	95	98	95	99	89	98
7,000	96	99	97	99	89	99
8,000	97	99	99	99	90	99
9,000	98	99	100	100	92	100
10,000	99	100	—	—	95	—
10,560 (2 miles)	99	—	—	—	96	—
Average walk	1,720	1,073	1,880	1,666	2,253	1,737
Median walk	1,070	810	1,120	1,130	1,250	1,405
Number of trips	17,306[a]	1,118	7,294	669	640	955

[a] Trips to home, delivery trips, other trips, and those with an unreported purpose totalling 6,630 are included in this figure but not shown separately.

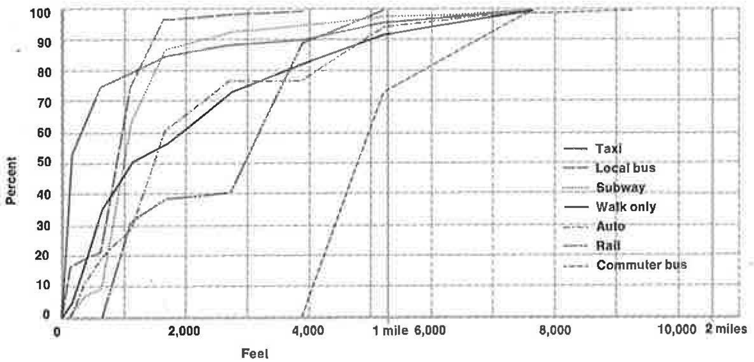

Figure 7. Cumulative walking distance distribution by mode.

TABLE 9

CUMULATIVE WALKING DISTANCE DISTRIBUTION, BY MODE, OF TRIPS TO WORK AT TWO OFFICE BUILDINGS

Walking Distance (ft)	Percentage of Trips Shorter Than the Indicated Distance						
	Taxi	Local Bus	Subway	Walk Only	Auto	Rail	Commuter Bus
250	50	18	3	10	5	0	0
500	70	20	8	25	15	0	0
750	77	35	23	39	21	0	0
1,000	79	62	50	47	26	23	0
1,250	81	81	69	52	36	33	0
1,500	83	90	80	55	51	36	0
1,750	85	97	88	58	62	39	0
2,000	86	98	89	61	66	40	0
3,000	89	99	93	76	76	51	0
4,000	91	100	95	83	78	90	5
5,000	95	–	97	90	91	98	60
5,280 (1 mile)	96	–	98	92	94	100	74
6,000	97	–	98	94	96	–	82
7,000	98	–	99	98	98	–	92
8,000	100	–	99	100	100	–	100
9,000	–	–	99	–	–	–	–
10,000	–	–	100	–	–	–	–
10,560 (2 miles)	–	–	–	–	–	–	–
Average walk	892	926	1,330	2,001	2,090	3,231	4,975
Median walk	160	890	1,010	1,100	1,490	2,970	4,820
Number of trips	347	641	2,827	807	409	1,057	228

94 percent walk less than a mile, and almost all walk less than 2 miles. However, the average walking distance is 1,720 ft, about a third of a mile, which is much higher than the median because of the distorting effect of the small proportion of very long trips.

The fact that almost 75 percent of the pedestrians studied do not walk all the way to their destination, but change to various mechanical modes of travel, suggests a closer look at walking distances in relation to the vehicular mode. In Table 9 the trips to work from Table 8 (which include return trips from other purposes at the two office buildings studied) are broken down by mode of travel. The cumulative walking distance distributions are shown in Figure 7. In addition, Table 9 gives the average and the median for each travel mode. It is clear that walking distance varies much more according to the vehicular mode than according to the purpose of travel.

The important message in Table 9 is the ranking of the different modes, with taxicabs having, quite plausibly, the shortest access distances, followed by buses and then by subways, and the commuter rail and bus terminals having the longest access distances—a function, again, of the relative scarcity of opportunities (there are only two rail terminals in midtown, whereas taxicabs or buses are ubiquitous). Interestingly, those who drive to work in the office buildings studied are willing to walk

TABLE 10

CUMULATIVE WALKING DISTANCE DISTRIBUTION AT SELECTED SUBWAY STATIONS AND PARKING FACILITIES

Walking Distance (ft)	Percentage of Trips Shorter Than the Indicated Distance			
	Three CBD Stations[a]	77 Lex IRT	Short-Term Parking	Long-Term Parking
250	17	7	19	9
500	31	16	46	16
750	44	27	49	23
1,000	56	36	55	37
1,250	64	46	65	47
1,500	69	56	70	56
1,750	74	64	75	61
2,000	80	70	80	68
3,000	95	92	88	82
4,000	98	100	98	92
5,000	99	–	99	97
5,280 (1 mile)	99	–	99	97
6,000	100	–	100	99
7,000	–	–	–	100
8,000	–	–	–	–
9,000	–	–	–	–
10,000	–	–	–	–
10,560 (2 miles)	–	–	–	–
Average walk	1,155	1,449	1,198	1,780
Median walk	900	1,380	700	1,220
Number of trips	32,611	6,336	31[b]	64[b]

[a] 53rd-Lex; 50th-6th; 42nd-6th IND stations.
[b] Observations, not expanded.

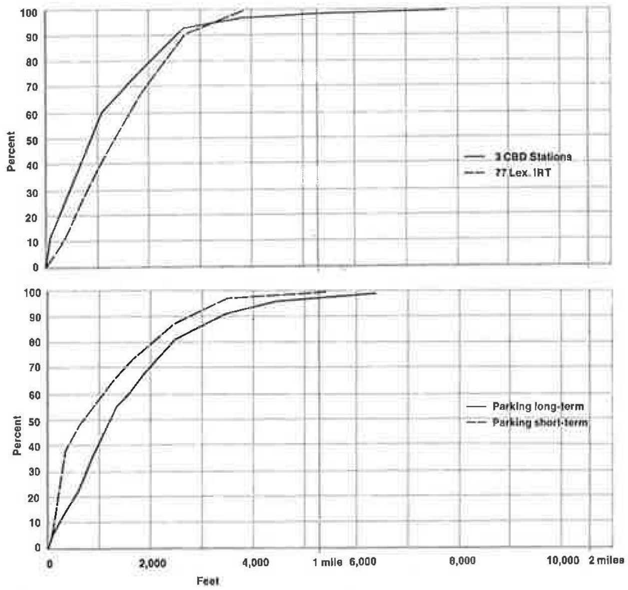

Figure 8. Cumulative walking distance distributions at parking lots and subway stations.

even farther than people on exclusively pedestrian trips—in fact, about three times the average distance reported for journey-to-work parking in cities over a half million in population (4). This reflects, to some extent, the high price of parking space in the vicinity of the buildings studied. The specific distances for walks to subway, rail, and commuter bus reflected in Tables 8 and 9 are also biased by the geographic location of the interviews and do not have general validity.

To obtain a more generally applicable measure of walking distances to subway stations and parking facilities in midtown, additional interviews were conducted, with the results given in Table 10 and Figure 8. Measured at stations, the walking distance to subways averages 1,155 ft in midtown and about 1,450 ft on the sparsely served East Side, and the respective medians are 900 and 1,380 ft. There is no significant difference between trips to work and trips for all purposes at these stations. Assuming an average walking speed of 285 ft per min (Table 7), the net walking time to the midtown stations averages about 4 min, that to the East Side station 5.1 min.

The walking distances for trip-to-work parking, if measured at the place of parking, have an average of about 1,800 ft and a median of about 1,200 ft. Both distances are about 500 ft shorter for short-term parkers.

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PEDESTRIAN CIRCULATION SYSTEMS IN CANADA

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This paper is concerned with delineating the conceptual aspects of planning for pedestrians and documenting the nature and extent of pedestrian circulation systems in Montreal, Toronto, and Calgary. Conceptual aspects are discussed within the planning framework and the Canadian context. The developments in Montreal, Toronto, and Calgary are discussed in detail. System characteristics, configurations, concepts, and linkages are described. Canadian experience appears to indicate that the theoretical concepts of pedestrian-vehicle segregation advocated for many years are being incorporated as planning principles. It would also appear that the state of pedestrian circulation planning and design in Canada is still a very empiric art. It seems apparent that no attempt has been made to evolve methods of benefit-cost analysis or determine optimum user-cost criteria. Although the surface road and sidewalk systems are built at public expense, it is assumed that private developers must pay for all or part of the segregated pedestrian systems. In all the three cities discussed, adequate linkages with the public transport system are being included. Although the general tendency seems to be to design underground pedestrian systems, above-ground systems are also being tried.

•PLANNING for the safety of pedestrians and pedestrian facilities has been a longstanding and worldwide problem. Urban traffic congestion is not peculiar to any specific geographical location or historical period; it appears in a variety of forms, and its universality suggests underlying factors that are only partially related to modes of transportation. The basic causes of urban traffic congestion appear to be excessive crowding of population and economic activity into small areas of land and a disorderly arrangement of land uses that has maximized transport requirements. The great bulk and density of urban buildings and the concentration of employment in the central business district have created a volume of passenger and freight movement that has become increasingly difficult to accommodate effectively regardless of transportation methods. The congestion of people, horses, and streetcars before the appearance of motor cars, the rush-hour madness of New York subways, and the lines of automobiles inching their way through traffic arteries are all manifestations of a continuing imbalance between transport demand and available transport capacity (1).

Today, the central business district by its very nature presents a challenging pedestrian pattern. The densities, diversification, and variety of physical development and economic activity provide a mixture of movements, both by foot and wheel, that makes the downtown configuration a composite of interrelated and interwoven patterns of activity. A pedestrian trip may be a terminal trip (the final leg of the trip in origin to destination), or it could be a separate pedestrian trip only. It may be for work, for pleasure, or for shopping. The pedestrian may be using the same streets, sidewalks, and routes for different types of trips during different times of the day or night, during different seasons, or under different circumstances of weather. The increasing densities of urban development and the increasing tempo of economic activity within the central business districts, combined with this tapestry of pedestrian movements, provides a challenge for planners and urban developers.

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Concern for pedestrian safety and the demand for higher environmental quality within the central business district emphasize the need to reexamine concepts of planning for the pedestrian and methods of urban design in major urban centers. The concept of a safe, separate, and exciting environment for walking is not new. Rudofsky points out that the problem of designing for pedestrian safety is of ancient origin. The covered street for pedestrian use only dates back to the Roman Empire and has survived in European cities to the present day (2). Ritter points out that vehicles were prohibited in the Forum at Pompeii, rebuilt 1900 years ago. It was designed as a super-block with seven culs-de-sac closed by bollard-like slabs. The size, speed, and scale of chariots and horses were already incompatible with certain pedestrian needs and functions related to social gatherings in the open. Segregation of pedestrians and vehicles was decreed by Julius Caesar in 46 B. C. in his Lex Julia Municipalis, which forbade heavy wagons within the limits of continuous habitation from dawn to dusk (3, 4). It is interesting to note that the design concepts used in Pompeii centuries ago are very similar to those used most recently in the new town of Stevenage in England. The architectural sketches developed in the 15th century showing vertical segregation of vehicles and pedestrians by Leonardo da Vinci were used in Adelphi by the Adams brothers.

Ritter and Rudofsky have both documented the significance of the concepts underlying the design of European city centers that have catered to vehicle-pedestrian segregation and coordination. To a large degree this has enhanced the environmental quality of older European cities compared to the drab, vehicle-clogged North American urban environments. The central business districts of most major cities in Canada and the United States are jam-packed with cars that are capable of speeds of more than 70 mph but actually move, on the average, at the approximate rate of a horse-drawn carriage used 100 years ago. Utterly inefficient as transport under present circumstances in city centers, these vehicles have at the same time become barriers to pedestrian circulation and divide the urban landscape with a continuum of metallic appendage.

Cumbernauld, near Glasgow, was the first of the new towns to apply the Radburn principle to segregate vehicles from pedestrians. Victor Gruen's plan for Fort Worth, Texas, visualized a square mile of traffic-free pedestrian precinct in the central business district. The town center of Stevenage includes a completely segregated pedestrian plaza in the city center. One of the largest and boldest examples of trying to achieve pedestrian-vehicle segregation is in the postwar reconstruction of Stockholm, Sweden. The Hotorget, the commercial center of downtown Stockholm, and the Sergels Torg areas provide extensive and well-designed pedestrian piazzas and precincts, completely segregated from all vehicles. West Berlin provides several examples of safe and continuous pleasant environments for pedestrian activity.

PLANNING STRATEGY

Planning Framework

Until 1962, pedestrian planning in Canada's downtown areas was simply a matter of providing adequate sidewalks and some traffic control at intersections. Very little consideration had been given to the dominant influence of major pedestrian trip generators (office blocks and department stores) and the major transport nodes (transit stations, transit stops, terminii, and parking areas). The pedestrian systems had generally followed fixed routes imposed by block and building layouts on streets primarily serving vehicles. Pedestrian systems had been secondary in importance to vehicular traffic systems.

Pedestrian activity does not constitute a major portion of the movements of all goods and persons. Especially in downtown areas, however, pedestrian movement is often the final part of a vehicular trip. These pedestrian movements are also the most flexible in terms of route choice and accessibility. Three aspects of pedestrian circulation are (a) the land use function that must be allocated space, (b) the transport linkage function connecting transportation nodes and downtown functions, and (c) a means of observing the urban environment for view and vistas. The system's purpose must be to move people from origin to destination, and it should not be considered as competitive with other transportation modes but rather complementary to them.

Quantitative Aspects

Pedestrian movement patterns are determined primarily by major generators such as large office-retail complexes and transportation nodes. The keys to the planning and development of the system are the distance and accessibility of these major trip determinants and their impact on the total volumes. These will determine the design capacity of pedestrian facilities, whether they are sidewalks, plazas, or separated systems.

Pedestrian planning to date has been largely on an ad hoc basis, and little work has been done to determine the demand characteristics, the impact of generators, and the development of analytical tools for analysis. Morris and Zisman argue that planning for pedestrians generally depends more on intuition than facts. The yardsticks and gages that have proved quite useful in determining highway needs are generally useless in making comparable analyses for planning for pedestrians (5).

A number of recent studies have dealt with pedestrian flows much in the same way as traffic studies, using origin-destination (OD) surveys, gravity models, and consideration of socioeconomic characteristics. Morris, for example, uses four categories of trip purposes—terminal, business, shopping, and miscellaneous—and proceeds to apply the gravity model techniques to data collected by regular OD techniques (6). Navin and Wheeler studied pedestrian flow characteristics on sidewalks to find patterns of capacity and use in relation to demand (7). Eyles and Spiller have discussed modal choice as it relates to the pedestrian (8).

To make quantitative analysis more meaningful, Stuart (9) suggests a number of questions that these kinds of data could be directed to answer:

1. How well are the pedestrian route locations aligned with the directions of heaviest travel demand? Can the need for any new routes be identified?
2. Which pedestrian routes require further development to resolve pedestrian circulation shortcomings?
3. Which sites within the existing pedestrian networks are preferred locations for the development of additional activities that generate pedestrian movements?
4. What will be the amount and directions of pedestrian travel resulting from the development of new generators at alternative locations? Will any adjustments in the pedestrian network be necessary?
5. What will be the volumes and circulation patterns of pedestrian movement expected from alternative land use arrangements? What types of networks will be appropriate?

Methods of data collection may parallel those of OD surveys used in metropolitan traffic studies. The major concern, however, must be centered on compatible location generators within a given network rather than developing networks for high-capacity, peak-hour operations. In general, the following kinds of information should be sought by pedestrian OD studies:

1. The location, scale, and character of major generators and their relationship to change-of-mode transportation nodes;
2. The scale, character, and purpose of pedestrian trips; and
3. Identification of route preference, choice, and flexibility.

Design Aspects

Before attempting to resolve vehicle-pedestrian conflicts, the preceding information should be gathered and analyzed; unfortunately, the reverse has occurred. The great mall movement was the fad from mid-1955 to 1963 (10). Wolfe has stated that there is a great emphasis on the panacea of the pedestrian mall, and one would hardly be caught with any plans that did not include this element (11).

Vehicle-Pedestrian Coordination—The two obvious solutions to the problem of pedestrian-vehicle conflict are coordination and segregation of vehicles and pedestrians. Most of the efforts in major cities in North American in recent years have been attempts to coordinate vehicle-pedestrian circulations within the same precincts. The techniques of traffic control currently in vogue represent responses to perhaps the most immediate problem concerning downtown circulation patterns, and the most significant attempts in quality and quantity have been at potential points of conflict between pedestrians and vehicles, particularly at route intersections.

Vehicle-Pedestrian Separation—Blachnicki and Browne argue that segregation of pedestrians and vehicles has now become essential. They state that we have now reached the stage where the extant road, which has changed very little since Roman times, will no longer do the job in the central business district (12). There are three basic ways of separating vehicles from pedestrians: (a) horizontal separation (the Radburn principle and the precinct); (b) vertical separation with the pedestrian underground; and (c) vertical separation with the pedestrian above ground.

The Radburn principle is basically an interlocking system of roads and footpaths that provides the best solution yet devised for residential areas. The precinct, or pedestrian island, method—a solution to the problem in central business districts—gives protection to the pedestrian but requires a great deal of space. Vertical separation has been tried in many cities by means of underground tunnels as well as above-ground skywalks. Blachnicki and Browne have documented several major recent developments that have used segregation as the basic method of design.

Segregation by Time—Segregation by time gives scope in areas where segregation in space is not possible either because of costs or other circumstances. Planning and design in this case are basically a matter of selecting the most suitable streets for this purpose. The grid system of streets used in most North American cities lends itself to segregation by time because parallel streets could accommodate the traffic while some of the streets are closed to vehicles. The selection of the right times for closing the streets depends on the shopping habits and the opening and closing hours of major generators along the pedestrian network. The key to success in this method is the ability to provide reasonable periods for service delivery in the mornings and the evenings. Where this has been possible, the idea of segregation by time is likely to be supported by the pedestrian as well as the owners of businesses along the street. Examples of the success of this method are Gotenburg in Sweden and Picadilly in London.

Environmental Elements

The environmental elements that influenced the planning and design of pedestrian circulation systems can be grouped into five categories, even though these five categories broadly represent only two elements, (a) the relationship of the pedestrian trip generators to the pedestrian network and (b) the details of urban design along the network and the imageability. These two basic elements are substantially interrelated. The physical location and the interrelationships of the generators influence the orientation and the dimensions of pedestrian networks and, to a large degree, determine the essential nature of design details. On the other hand, the planning and location of the pedestrian network itself will influence further opportunities for location and relocation of important pedestrian trip generators.

The five basic environmental elements can be grouped as follows:

1. Movement patterns—safety, comfort, and continuity of the pedestrian network and available alternative route choices;
2. Location of major trip generators—interconnections between the major trip generators themselves and their relationship to the pedestrian network;
3. Nodal elements—change of node points, such as parking areas, transit stations, and transit stops, and recreational areas, such as squares and parks;
4. Historical elements—unique landmarks and distinctive assets of history, architecture, and even topography; and
5. Imageability—urban design facade, view of and from the network, and vista.

These evironmental factors relate to the scale sensitivity and subtleness of those who are to move along the pedestrian networks at a flexible speed with a number of route choices open to them. Physical and biological detail of the urban scene comes into its own for the pedestrian as he moves along his path. The basic structure of the formation of pedestrian spaces contributes significantly to visual diversity. Major elements, either man-made or natural, within the pedestrian system make possible a differentiation among subareas of the environment (13). This is an important determinant of the environmental character of the network itself.

There is no strong evidence to support the view that totally segregated systems are completely preferred. The choice between separation and coordination appears to be relatively open. However, in urban areas where intensity of pedestrian activity is very high and coordination with existing street patterns cannot effectively be made, the segregated systems appear to have provided a measure of success.

Economic Aspects

The costs, benefits, and community consequences of providing viable and aesthetic pedestrian circulation systems must be evaluated within the framework of the total transportation system. The cost-benefit criteria must also be based on systems alternatives, not on the evaluation of single elements of the system. For example, the segregation of vehicles and pedestrians will obviously result either in higher motor-vehicle handling capacity in the existing streets or in higher comfort and safety both to motor vehicle users and pedestrians. In downtown areas a large percentage of the pedestrians would also be users of other vehicular systems. The traditional tools of cost-benefit analysis applied to highway and street planning have not been used at all in planning for pedestrians, and in fact they may not be relevant.

To date many of the major segregated pedestrian circulation systems in Canada and the United States have been developed in conjunction with major private urban developments. The private-public interaction has been limited to design standards and, to a small degree, attempts to make possible the development part of an overall pedestrian system. Most arrangements for cost sharing between private and public enterprise have been ad hoc and based on circumstantial expediency in which the approval or disapproval of the proposed major urban development (office buildings, shopping centers, department store complexes, etc.) has been the prime objective. It is necessary therefore to evolve methods of cost-benefit analysis that would include an analysis of socioeconomic and environmental consequences within the overall framework of the total transportation system. In a sense, civic governments must take the initiative in developing and evolving plans for a total transportation system.

Segregation often involves substantial additional costs, and the questions of who benefits and who should pay are difficult ones to resolve. The system users and the planners can easily see the benefits and change in comfort, safety, aesthetics, and perhaps traffic efficiency in the central business district. These are the factors that encourage and justify the development of pedestrian systems in conjunction with major urban developments. However, it is argued that pecuniary benefits do accrue to commercial establishments, whether existing or proposed, due to greater pedestrian access that results in increased patronage. The cost-sharing arrangements followed hitherto in Canadian cities reflects some realization on the part of civic governments and private entrepreneurs that benefits accrue to both sides and are not mutually exclusive.

To make it possible to develop a total pedestrian circulation system, some control must be exercised over the location and development of major pedestrian trip generators that in turn affect route choices, patterns, and linkages and to a large degree determine pedestrian volumes. The planners should coordinate these developments to the extent that the proposed pedestrian system and the locational characteristics of the major developments are mutually compatible and enhance environmental quality. The provision of related environmental amenities such as mini-parks, plazas, and nodal points must obviously be a civic responsibility.

Choice Limitations

Whether the pedestrian is going to be below or above the level of the motor vehicles is going to be influenced not only by cost-benefit analyses but also by other limiting factors such as topography, existing building design, geology, excavation costs, cost of relocation of facilities, groundwater levels, aesthetic surroundings, pedestrian psychology, and accessibility levels. Climate and the surrounding vista play very important roles in determining the type of segration that is desirable. For example, in Montreal the initial pedestrian systems utilized below-grade connections, influenced primarily by desire for climate control and subway access. In Calgary, however, the high water table completely rules out any underground pedestrian systems. The view of the mountains and the sea, providing an enviable vista in Vancouver, may rule out underground systems there. All of these choice elements must be a part of the systems analysis that precedes the design and development of a pedestrian network.

THE CANADIAN CONTEXT

Some of the major Canadian cities have been developing segregated pedestrian systems in recent years. The more notable ones are in Montreal, Toronto, and Calgary. It is significant to point out that approximately a fourth of the total population of Canada lives in these three major cities. All of these cities have opted for some type of segregated pedestrian system. This study is an endeavor to document major downtown pedestrian circulation systems in these Canadian cities.

The Montreal System

The Montreal system (Fig. 1) began in 1962 with the construction of Place Ville Marie. Initially it provided a linkage between the below-grade shopping mall and its associated 42-story office tower with the Canadian National Railway Station concourse and the Queen Elizabeth Hotel.

Subsequent large developments in downtown Montreal have incorporated below-grade shopping concourses and provide pedestrian linkages to hotels, offices, and transportation nodes. The existing system is continuous and connects Place Ville Marie, Queen Elizabeth Hotel, Canadian National and Canadian Pacific Railway Stations, Place Bonaventure, Place du Canada, and Hotel Champlain and has connections to Metro Station at Bonaventure. The developers of another adjacent system, Place de la Bourse, Place Victoria, Metro Station Victoria, and the Stock Exchange, are negotiating a connection to the Bonaventure-Place Ville Marie system. Similar schemes, not connected directly but with access via Metro, are at the Morgan's and Eaton's Department Stores, Atwater, Berri de Montiguy, and peripheral Metro stations.

The Montreal system is essentially a below-grade climate-controlled system of enclosed malls and connecting passageways, now totaling approximately 2 miles of passageways and giving direct access to some 40 acres of prime office, hotel, and shopping developments, including 300 underground shops, 50 restaurants, and 2,500 hotel rooms (14). The system is not yet complete, and future developments are proposed connecting Cité Concordia (Marathon Realty's proposed Windsor Station scheme) and other major generators. Some concern is expressed by planners and engineers that the system may develop to be too large and therefore lose its pedestrian-scale characteristics (15).

The 1964 Downtown Report noted that there were interesting possibilities in the Place Ville Marie developments, the subway mezzanines, and the proposed Place Bonaventure complex (16). It was further suggested that Metro stations, integrated with public squares that figure prominently in Montreal development history, might play a polarizing role in the downtown area (16).

The Montreal system was "unplanned"; each developer has initiated his own scheme, including connections under city streets. The original scheme (Place Ville Marie) proponents were Vince Ponte, a project architect, and M. Gariepy, Planning Department Architect; subsequently, many more planners, architects, and developers became involved. The total scheme, though, appears to suffer from its original lack of planning and at many points can hardly be called a system at all. It also suffers greatly from a lack of visual relationship between all the movement systems of the new core (17). Considerable developments have taken place, confirming the ideas of the 1964 Report. The system has always developed on an ad hoc basis, without developmental guidelines or even standards. Recently, however, the City Planning Department has initiated studies

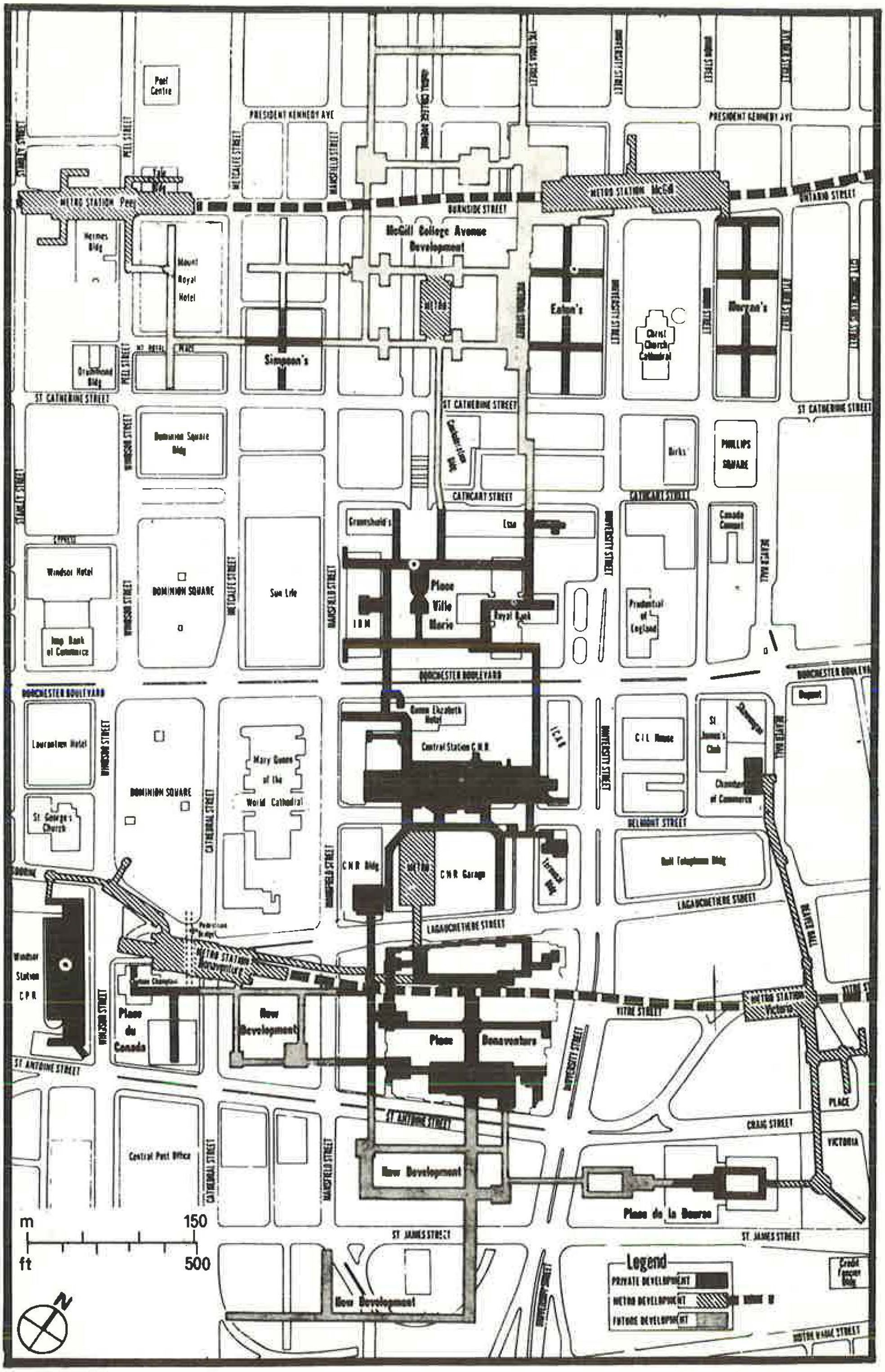

Figure 1. Montreal: segregated pedestrian system.

and developed a concept for the future system. As long as developers are willing to build these systems, the city will permit them.

The apparent success of the existing system, including the Metro system, determines in part that other developers will follow suit. Future plans call for a development, with pedestrian systems, between Place Bonaventure and Place du Canada (Chateau Champlain), with a possible connection east to Place Victoria and Place de le Bourse and extensions north from Place Ville Marie to Sherbrooke, connecting with Peel and McGill Metro Stations. Recently, Canadian Pacific Railway announced plans for a $250-million complex at Windsor Station and the Laurentian Hotel site, with at least three 60-story skyscrapers that would incorporate pedestrian mall systems.

Some thought has been given to development of the system to the south, although again no formal documents or policy exist. The present schemes are all in the newly developing center of the city. Montreal recognizes another axis of downtown life, centering on Place Victoria and the financial center. This is partly "old Montreal" that has been refurbished. It also includes the city administrative center, the new Quebec Palais de Justice, l'Hotel de Ville, and other civic buildings. The proposals for this area call for an elevated pedestrian system to conform more closely with the levels of the newer downtown.

The elevated system is rather controversial. Any advantages of conforming to the present system levels and being oriented through visual connection appear to be outweighed by the aesthetic unpleasantness of skywalks. On the other hand, an elevated system seems to be favored, especially if the pedestrian circulation system can be carried through buildings, over alleyways, and across streets in broad skywalks such as the one from Place du Canada to Dominion Square, rather than underground walks no more than 8 ft wide.

In this financial-administrative area, the city and the Province of Quebec are major landowners and users. Therefore any pedestrian system built here would have to be paid for by the city and the province. The scheme is as yet only being talked about, with no formal commitment from the city (18).

Whether the system is underground or above ground two basic principles remain. First, a climate-controlled environment is important because of the rigorous winters experienced in Montreal. Climate control is not only extended to the shopping concourses and connections but to the entire system. Access to the system is "enclosed" through subway connections and the Autoroute Bonaventure, which gives direct access to major parking garages. Some problems with excessive wind from Metro and the tunnel nature of the system have been experienced. Heating and air conditioning costs are offset by lower maintenance costs for cleaning (especially winter snow and slush). The second principle that is the basis for involvement of the city is the acceptance of segregation of vehicular and pedestrian traffic. It has been noted that the vehicular congestion and accidents involving pedestrians on downtown streets have been reduced because of the underground pedestrian system (19).

The Toronto System

Toronto's underground pedestrian circulation system is less developed than Montreal's. It contains shopping malls in the Toronto-Dominion Center and the Richmond-Adelaide Building (Fig. 2) and various smaller parts, including a below-grade pedestrian link from the Union Station (C. N. R. and C. P. R.) to the Royal York Hotel and connections from the subway system to Eaton's and Simpson's Department Stores. Segregated pedestrian linkages are planned at proposed shopping concourses at Commerce Court with connection to the subway. The proposed Sheraton Hotel plan has a segregated pedestrian link with the new City Hall and the Richmond-Adelaide Center. All these developments appear to be part of a plan to develop a segregated underground pedestrian circulation system in downtown Toronto by 1980.

The Toronto system is being developed by individual developers, with active participation and some funding by the city. City planners have been closely involved in planning the overall system and do exert some control over it.

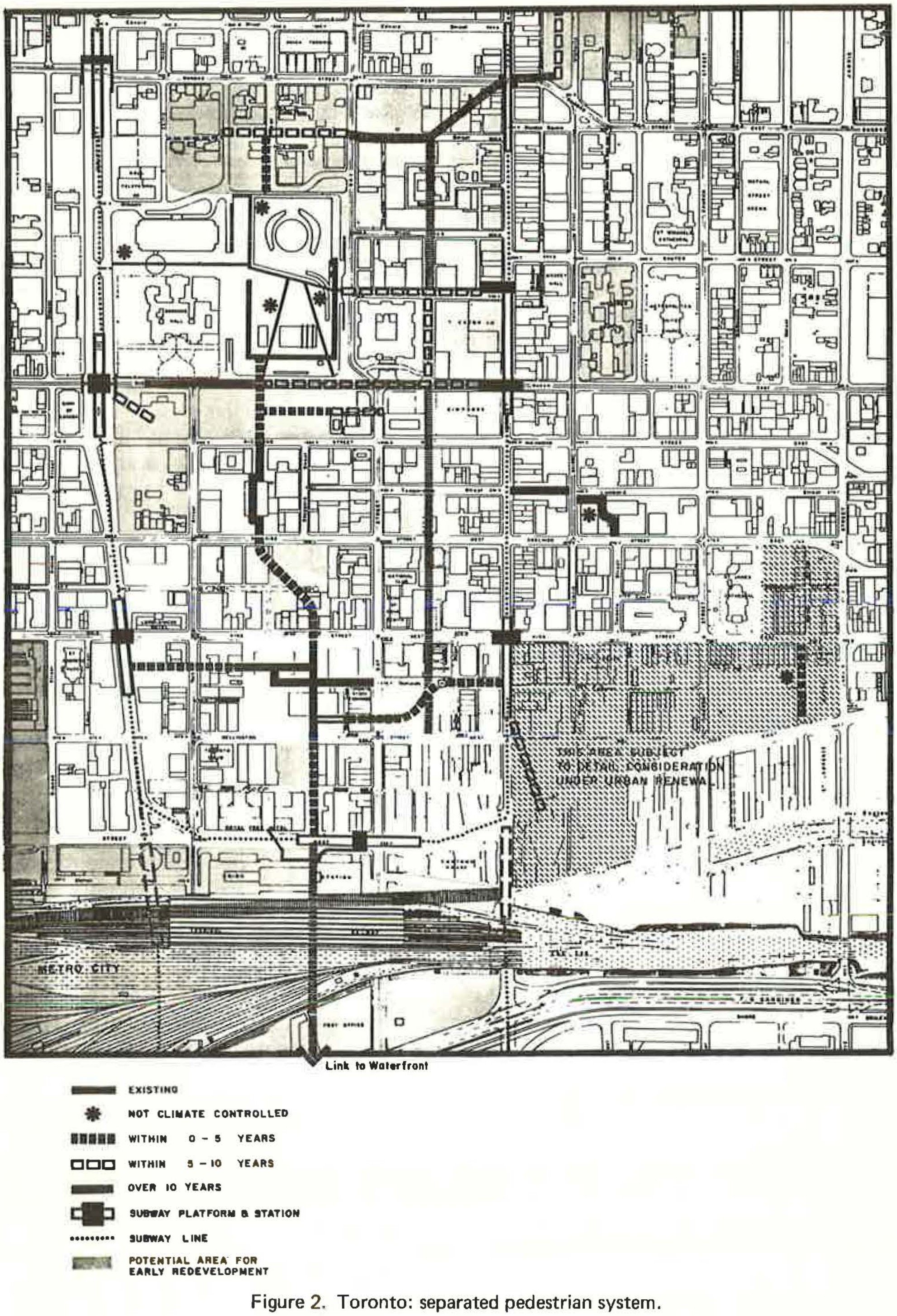

Figure 2. Toronto: separated pedestrian system.

The Toronto concept is similar to Montreal's. In general the major generators such as shopping concourses and hotels are linked with change-of-mode transport nodes. The Montreal system stresses climate control, segregation, and linkages in a subterranean environment, whereas the Toronto concept stresses similar elements in a below- and at-grade open environment (20).

The pedestrian system at present has over ½ mile of nonconnected passageways and concourses, with another ¼ mile under construction. As can be seen from Figure 2, the system envisages a north-south spine with two or more extending arms and the Toronto-Dominion Center at the hub. A connector is being constructed between the City Hall and the Richmond-Adelaide Center, along with two active proposals providing links south to the Toronto-Dominion center in the near future. These are all below street level and serve as passageways (21).

The Toronto Transit Commission, an agency of the municipality that owns and operates the subway system, takes an active part in the development of the segregated pedestrian circulation network. The commission has proposed and worked toward developing direct linkages to subway stations and entrances from all possible major trip generators.

As in Montreal, the Toronto system gradually jelled, but with more preplanning by civic officials and active encouragement and financial assistance by civic governments. The systems guidelines for development and concepts of the scheme have been formalized. Toronto realizes that the total image of the city and its ability to attract investment "... depends a good deal on the ease, the freedom, and the pleasure with which people can move about on foot" (22).

The concept of segregation of pedestrians from vehicles is paramount to relieve traffic congestion, both vehicular and pedestrian, improve traffic flows, and provide safer movement. The segregated system affords an opportunity for some measure of climate control. It is also a useful means of improving the quality of the downtown area through provision of plazas and green space, and it can provide a better place to stroll than can an unsegregated sidewalk (22).

One of the major principles is that the system is an "open" system, not enclosed, and the system should not be excluded from the street-level downtown environment. This negates overall climatic control but should provide a more pleasant human experience. Design guidelines indicate this and emphasize the concern for variety of experiences, open space, quality of service, street furniture, and continuity of the system (22). The open system and the development concepts are exemplified by the Metro Center development proposals. In describing the connections from the GO trains (Government of Ontario Commuter Trains) to downtown, Metro Center proposals indicate that connections should become an orientation place where the user can see the outdoor courtyards, shopping ways, and foyer areas all at once. In this respect it is one step further than the light wells of Place Ville Marie that, although they do bring the vision of outdoor space into shopping malls, do not orient the user into the total organization of the scheme (23).

Three portions of the existing system were developed independently, and these form the nucleus for the projected pedestrian circulation system. The first is the subway station at Queen and Yonge, with its connections into Eaton's and Simpson's. Metro Transit is also responsible for many other smaller links and is actively planning more to integrate into the proposed system.

The second segment is the link from the Canadian Pacific-Canadian National Union Station under Front Street to the Royal York Hotel. This link is little used, however, being old, narrow, and slightly unpleasant, and is expected to be replaced in the future either by the city or by Metro Center developers.

The third component is the underground concourse of the Toronto-Dominion Center. Although a pedestrian system had been proposed in various forms since the subway system was opened, the Toronto-Dominion Center made possible the development of an overall scheme. The Center is a twin-tower office complex with a below-grade shopping concourse containing approximately 50 shops. At present no cross-street connections exist, although provisions were made during design and construction and connections are bulkheaded at lot boundaries (24).

The proposed system is outlined in a City of Toronto publication that describes the rationale, connections, legal arrangements, and civic participation (22). It takes the form of an elongated cross, the north-south axis from the City Hall to Union Station, and an east-west axis at King Street, with the Toronto-Dominion Center at the cross (Fig. 2). Various smaller side shoots are planned, especially east of City Hall in an area scheduled for redevelopment by Eaton's. This Eaton's development area has been the subject of many proposals, the majority of which contain segregated pedestrian systems. The current proposal is to link Eaton's and associated shopping malls to the subway, Simpson's, and City Hall at below-grade and above-grade levels (25). Civic officials appear to be discouraging skywalk proposals.

Two key links in the north-south axis are now actively being pursued. South of City Hall, the Four Seasons Sheraton Hotel and Thompson Office Building are providing links to Nathan Phillips Square and the Richmond-Adelaide Center as a condition of sale of this city-owned property. Between the Richmond-Adelaide Center and the Toronto-Dominion Center another major office development by Imperial-York will incorporate a segregated pedestrian system connecting north and south.

One of the more useful connections would be north of the proposed Metro Center. This complex, built on air space over the Canadian National-Canadian Pacific Union Station, would have 20,000 residents and 40,000 daytime office workers and act as a transportation terminus and linkage for regular Canadian National-Canadian Pacific trains, GO trains, Greyhound Bus Depot, Airporter Bus, and Metro Transit subway. A segregated pedestrian system is an integral part of the packaged scheme, connecting under Front Street to the downtown. Metro Center is reluctant to provide this link, believing it to be a city responsibility (26). An interrelated transportation system will only operate effectively if pedestrian facilities provide quick, convenient connections with the various elements. Also, to encourage desirable development these pedestrian connections must link the Metro Center with the downtown and waterfront (27).

One part of an east-west link is under construction at Commerce Court opposite the Toronto-Dominion Center, on Bay Street, with connections to the subway system and tentatively to the Stock Exchange. Negotiations are under way to link these two developments.

Further links are proposed for the 1970-1980 period from the cross spine within the confines of the densely built-up downtown. The City Planning Department has outlined a series of segregated pedestrian systems in the uptown area of Bloor Street connected to the subway stations. One development at Bloor and Yonge, a twin 30-story office-hotel-shopping complex with 1.5 million sq ft of floor space that will connect into the subway and form the nucleus of the proposed uptown system, is segregated from vehicular traffic and will operate above, below, and at grade (28).

The Calgary +15 System

Calgary's pedestrian system is less developed than either Montreal's or Toronto's. Its uniqueness is that it is the only elevated system in Canada. As in Toronto, the city planners feel that some direct relationship with the downtown environment is essential (29).

Underlying the +15 concept are a series of elevated and ground-level plazas and walkways with skywalks that utilize existing interior building layouts and mid-block connections to serve the downtown core area (Fig. 3).

In contrast to the Montreal and Toronto systems, where private developers initiated construction and connection points were later introduced, the Calgary system was conceived by the City Planning Department. Some developers are still reluctant to integrate into the system (30). Montreal and Toronto feature total climate control, whereas Calgary does not—even though segregation is a major objective. To date 31 buildings and other developments have the +15 features, but few interconnections have been proposed. Because the system has not yet been officially approved by the city council, all +15 features incorporated into developments have come through negotiation and persuasion.

Calgary's +15 concept originated from three major studies (29, 31, 32). The 1967 Master Plan proposing a strong downtown emphasizes the need to (a) create a good pe-

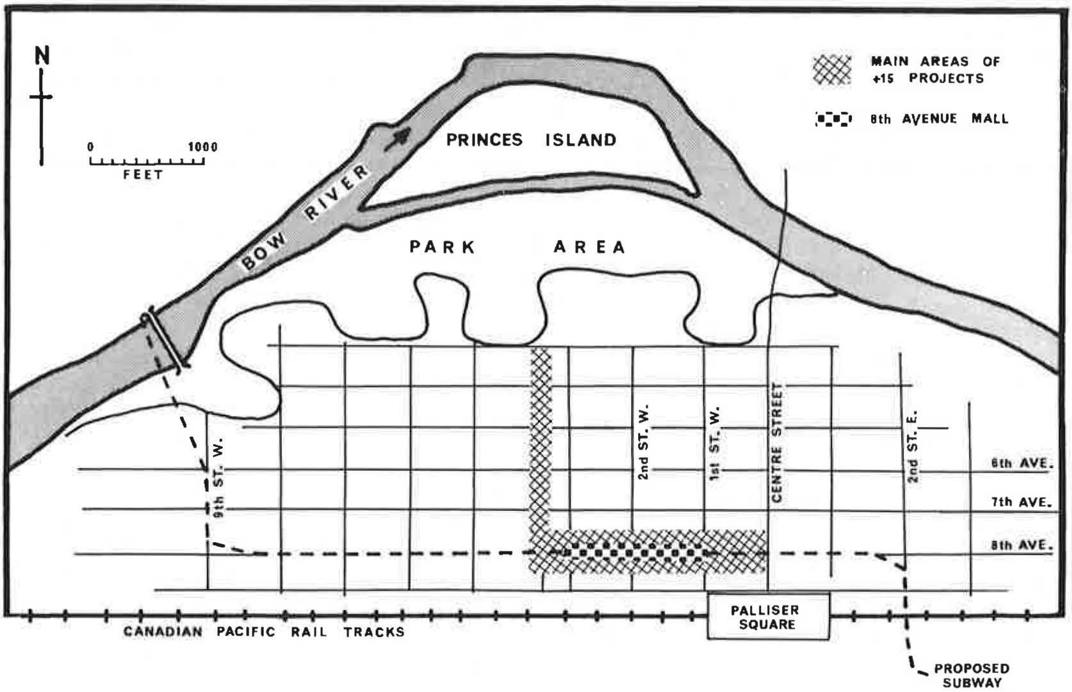

Figure 3. Calgary: downtown area to be served by +15 system.

destrian environment, (b) improve pedestrian and vehicular circulation, (c) connect major buildings and places of interest, and (d) create good pedestrian access.

The +15 concept is primarily concentrated in the core of downtown. This is a 180-acre area of high-density development that is considered adequate for strengthening the core without making it too large for normal walking distances. The principle of segregated pedestrian walkways, shopping malls, plazas, and closed streets was adopted as being more desirable than street widening or restricting future development densities. With the enormous capital already involved in servicing buildings by vehicles at street level, future vehicular traffic would remain at grade. A vertical and horizontal separation was called for.

Relying on preliminary experience with systems in Montreal, Toronto, and U.S. cities, the planning department opted for an at-grade and above-grade system that would segregate vehicles from pedestrians, provide protection from the harsh winter climate, and create environmental interest. An upper-level pedestrian system was preferred to an underground system because it could (a) create a more acceptable walking environment, (b) avoid the expense of combatting a high water table, (c) eliminate the costly relocation of underground utilities, (d) improve accessibility to and within buildings, (e) avoid the high cost of excavation, and (f) provide direct access over rail and road and reduce the poor visual and economic impact of railways (33).

The system is similar to Toronto's, where climate control was considered desirable but not essential and where open space was to be provided in the form of plazas and ground-level malls. The design term +15 refers to approximate development height, 15 ft being the minimum clearance required over streets and lanes.

Development of the downtown area to incorporate +15 features depends on the use of development control techniques rather than zoning control. As an incentive, floor-space ratio bonuses are given to those developers adhering to the +15 system. Four major arteries constitute the framework within which the system is to be developed. Bow Trail, circling downtown on the north, is a major traffic distributor. Seventh Avenue will be a major bus transit artery, with Center Street as the rapid transit artery. Eighth

Avenue is designated as a major pedestrian artery and is now a pedestrian mall. To date two blocks of this artery have been developed and are well used. Seventh and Eighth Avenues link with downtown parking facilities, high-rise residential and office buildings, the retail core, and civic and institutional areas.

Walkways and plazas are proposed to be integrated into future developments without conflicting with existing amenities. The concept's comprehensive design standards, incentives, and guidelines have been well documented and are available as guidelines to developers (33). Despite the general enthusiasm from citizens and developers, the concept has not been officially adopted by the city council. Development to date has been achieved through the use of selective development control techniques and through the voluntary intent of developers, the council having endorsed projects individually. Since the inception of the scheme there have been 31 developments constructed or approved for construction, with a total value of approximately a half billion dollars and providing 2 miles of walkways and plazas (30). Few parts are interconnected, beyond store to promenade walkways and a walkway at Calgary Place to Calgary Inn on Fourth Avenue, and the more intensive development is in the retail core and toward the Palliser Center and Husky Tower.

Despite the lack of formal approval, without which the city cannot develop its share of mini-parks and plazas except on a piecemeal basis, the scheme is off the ground and appears to be a success. Most developers have been enthusiastic about the scheme and consider it well thought out, imaginative, and, above all, economically viable. The developers seem to realize that returns from two-level shopping are greater, and they appear to benefit from floor-space ratio bonuses.

The main thrust of the planning department, in addition to the development incentives and bonuses, is that some projects have already been constructed with the necessary facilities so that the +15 proposals can be incorporated. This makes future developers more disposed toward the system on the grounds that the existing buildings and shops will be obsolete and ready for redevelopment when the system is more fully under way. The most important projects have been the C. P. R. Palliser Square (complex of hotels, transportation, shopping, and observation tower) and Calgary Place (office and retail complex). Another incentive has been the closing of two blocks on Eighth Avenue to vehicular traffic. This is now a pedestrian mall, an experiment that took 2 years to be fully acceptable.

CONCLUSIONS

Canadian experience discussed in this paper would support the following conclusions:

1. Theoretical concepts of pedestrian-vehicle segregation advocated by Ritter and Rudofsky (2, 3) are being incorporated, although not consciously, as planning principles in high-density downtown areas.
2. The state of pedestrian circulation planning and design is still a very empiric art rather than supported by rigorous analytical criteria. Experience and techniques of the highway field seem to be unavailable or not used in determining the characteristics of pedestrian systems, supporting the conclusions of earlier research by Morris (6).
3. A planning framework suggested by Stuart (9) appears to be the overall basis for planning, but the quantitative aspects are treated only superficially.
4. The segregation-by-time concept suggested by Blachnicki and Browne (12) appears not relevant to the Canadian context.
5. Among the environmental elements discussed previously, only the relationships of the system to major trip generators and nodal elements are considered important. Environmental comfort, safety, and imageability are still largely ignored.
6. No attempt has been made to evolve methods of benefit-cost analysis or to determine optimum user-cost criteria. Although the surface road and sidewalk systems are built at public expense, it is assumed that private developers must pay for all or part of the segregated pedestrian systems. The assumption here is that such a system would benefit the developers immensely. A complicated system of floor-space ratio bonuses (indirect subsidies) and cost-sharing arrangements are made in each case.

7. Adequate linkages to subway stations and transit stops are considered essential. These linkages are carefully planned by the city and the transit and are built at public expense.

8. Where there are very high densities and transport nodal linkages are good, private developers are willing to pay for or build the required system components.

9. There appears to be a reduction of accidents on surface streets and noticeable traffic relief due to segregated systems.

10. Although the general tendency is to design underground pedestrian systems, above-ground systems are also being tried. It is too soon to compare and analyze user response patterns to these two methods of vehicle-pedestrian segregation.

ACKNOWLEDGMENTS

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PEDESTRIAN WAY CONCEPTS AND CASE STUDIES

Herbert S. Levinson, Wilbur Smith and Associates

This paper describes pedestrian circulation concepts for the southwest employment area in Washington, D.C., and for downtown Seattle, Washington. These case studies indicate the importance of achieving pedestrian movement continuity, separating pedestrian and vehicle improvements, and preserving pedestrian movement corridors.

•PEDESTRIAN circulation is an important part of the total movement system of central business districts, airports, university campuses, and other major activity centers. It is an essential transportation planning function because each trip by auto, bus, or rapid transit begins or ends with pedestrian movement.

Pedestrian circulation planning follows the same general procedures used in comprehensive land use and transportation studies; steps include inventory and reconnaissance, analyses and projections, concept and alternative development, and plan formulation and appraisal. There are, however, obvious differences in scale, role of concept and joint development, and extent of private group participation. A freeway plan, for example, is regional in scale, whereas a plan for pedestrians focuses on a small geographic area.

Pedestrian travel has characteristics not found in vehicular movement. Most pedestrian trips are short in length—usually less than 2 blocks—and are highly concentrated in core areas. These trips mainly reflect movements (a) from parking and transit terminals to places of work, (b) between stores (and offices) in the retail core, and (c) interbuilding trips—often for business or dining purposes. They are far more localized than either bus passenger or automobile flows (1).

Two case studies are presented to illustrate concepts and approaches to pedestrian circulation planning. These are a pedestrian circulation plan for the southwest employment area in Washington, D.C. (2), and a pedestrian plan for downtown Seattle, Washington (3).

WASHINGTON PEDESTRIAN CIRCULATION PLAN

The southwest employment area reflects the dramatic urban renaissance taking place in the nation's capital. A 248-acre area, bounded by 15th Street and Maine Avenue on the west, Jefferson Drive on the north, South Capitol and Canal Streets on the east, and the Southwest Freeway on the south, it has become the city's second largest employment center, exceeded only by the long-established downtown area.

Employment in this area is now approximately 60,000 persons and is expected to reach 83,000 by 1975 and 100,000 by 1990. Employment in 1990 in this area will likely exceed that found today in downtown Atlanta, Baltimore, or Pittsburgh and will approach the density of Chicago's Loop—over 400 persons per acre (Table 1).

Movement Problems

Because of its proximity to downtown Washington, relative isolation from major population concentrations, and rapidly expanding employment, the area's transportation problems have increased. Although it is relatively easy to travel through or around the area, local street access is limited by the Mall, Southwest and Center Leg Free-

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Sponsored by Committee on Pedestrians and Committee on Parking and Terminals and presented at the 50th Annual Meeting.

TABLE 1

COMPARATIVE EMPLOYMENT DENSITIES IN SELECTED MAJOR ACTIVITY CENTERS

Location	Current Downtown Employment	Area in Acres	Employment Density, Employees per Acre (rounded)
Chicago	300,000	680	440
Federal Triangle	22,000	70	315
Pittsburgh	95,000	320	295
Seattle	55,000	200	275
Los Angeles	120,000	470	255
St. Louis	119,000	540	220
Houston	119,000	580	205
Atlanta	75,000	380	200
Washington	212,000	1,090	195
Cleveland	124,000	660	185
Baltimore	80,000	490	165
Denver	50,000	340	145
Kansas City	65,000	580	110
Nashville	34,000	370	90
Southwest employment area			
1968	38,000	248	155
1970	61,000	248	245
1975	83,000	248	335
1990	99,000	248	400

ways, and the Penn Central Railroad. Discontinuities are common, internal circulation is difficult, and around-the-block circulation is often impossible.

Pedestrian circulation patterns and problems mainly reflect the linkages of existing employment concentrations with streets, bus lines, and major parking areas. Movements take place along 9 miles of existing street sidewalks, of which 50 percent are less than 6 ft wide. Movement is heaviest adjacent to major employment centers and peaks sharply during rush hours; approximately 12,000 of the 55,000 federal employees leave the area during the evening peak 15 min.

Planning largely has been confined to individual building complexes. Consequently, many of the amenities normally associated with large-scale integrated urban developments are not provided. Separation of vehicular and pedestrian traffic is limited to a few locations, streets and sidewalks are crowded, and peak-hour congestion is common.

Present peak-hour vehicular and pedestrian movements are shown in Figures 1 and 2. Sidewalk congestion is concentrated along 7th Street between D Street and Independence Avenue. Pedestrian-vehicle conflicts are especially pronounced at the intersections of 7th Street with Independence Avenue and D Street where peak-hour crosswalk volumes exceed 1,500 persons per hour. Narrow and congested sidewalks are also found along D Street to the west of 7th Street.

Effective communication is further impeded by long walking distances, unattractive railroad underpasses, crossings of heavily traveled streets, and exposure to weather. Pedestrian ways are mainly limited to L'Enfant Plaza, the 10th Street Mall, and the special walkways connecting parts of the Departments of Agriculture and Health, Education and Welfare complexes.

Anticipated increases in employment will bring about new pedestrian movement patterns and problems. Conditions will become especially critical during the period immediately prior to Metro (subway) construction, when peak-hour walkway volumes will approach 3,000 persons at the 7th and D and 7th and Independence intersections.

The reorientation of pedestrian movements to the three Metro stations (12th and Independence, 7th and D, and 4th and D Streets) will reduce pedestrian movements in the 7th and D Street core but will significantly increase pedestrian volumes adjacent to planned Metro entrances; over 7,500 persons per hour are anticipated along the south side of Independence Avenue west of 12th Street, over 5,000 persons per hour on the south side of D Street west of 3rd Street, and over 2,500 persons on the west side of 7th Street south of Maryland Avenue (Fig. 3). These densities could produce serious sidewalk congestion unless additional subway entrance facilities are provided.

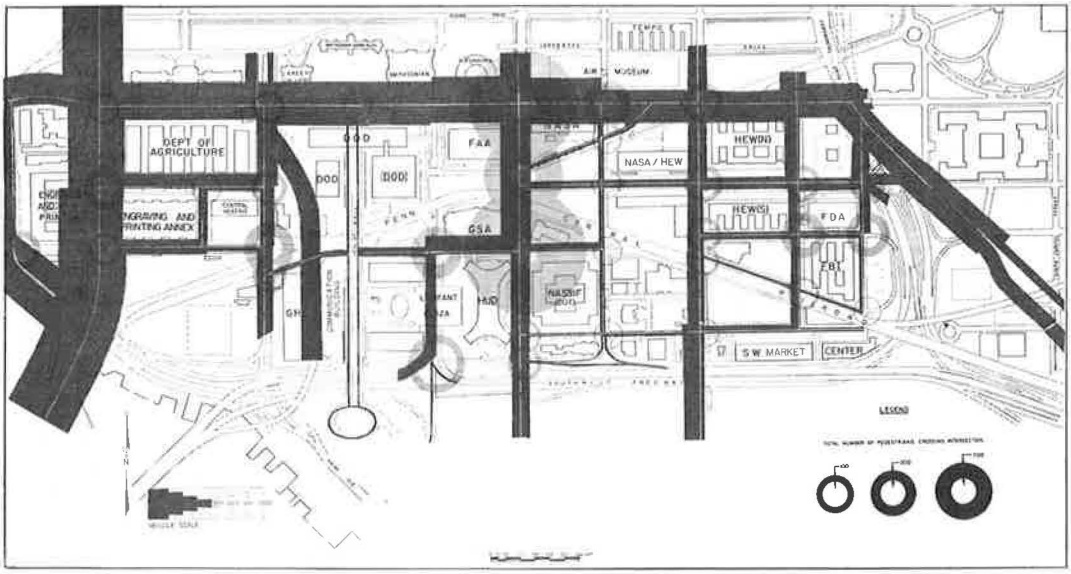


Figure 1. Peak-hour pedestrian and vehicle conflicts (1968 day, p.m.).

The need for improved circulation in the area is widely recognized, and transportation services have been continually upgraded to meet increased demands. A pedestrian circulation plan is an essential complement to existing and proposed regional transportation facilities.

Circulation Concepts

Pedestrian circulation planning should reflect the coordinated transport needs of the entire area rather than individual requirements of specific buildings—each considered

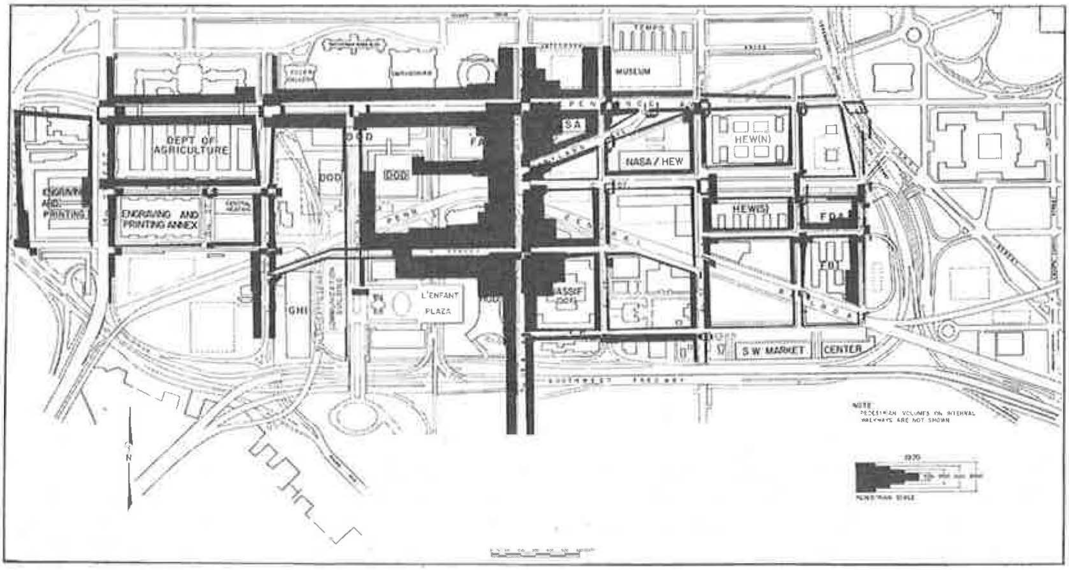


Figure 2. Peak-hour pedestrian volumes (1970, p.m.).

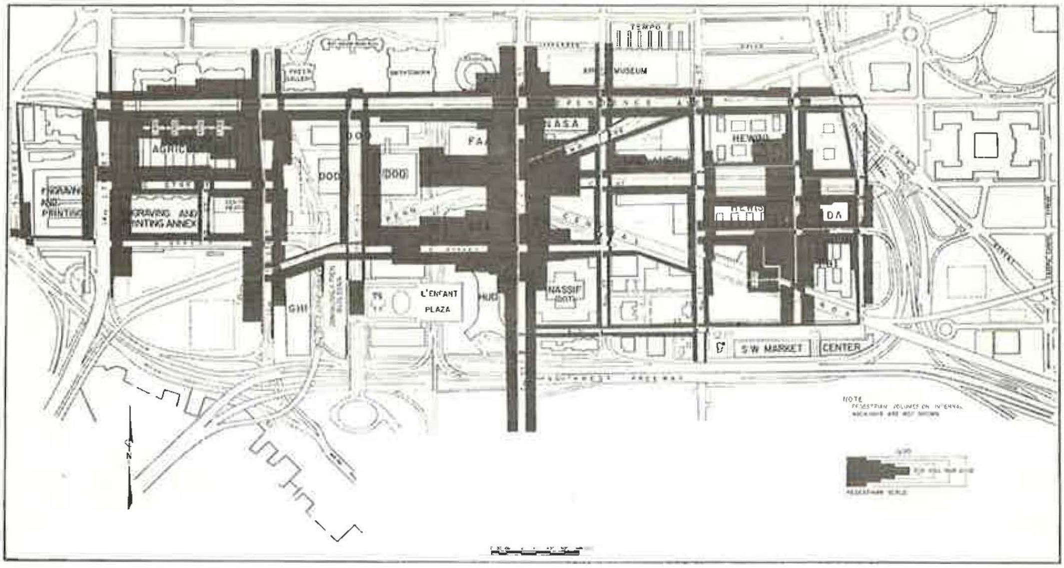


Figure 3. Peak-hour pedestrian volumes (1990, p.m.).

in isolation. Pedestrian movement is far too complex to be solved by parochial or fragmented approaches.

The pedestrian system should incorporate a wide variety of movement methods. These include (a) sidewalks, skywalks, and subwalks; (b) malls, plazas, concourses, and building arcades; (c) ramps; (b) escalators and automated ramp systems; (e) elevators; (f) pedestrian assists; and (g) micro-systems ("people movers").

The following pedestrian circulation concepts, shown in Figure 4, also have general applicability:

1. Pedestrian ways should be carefully related to existing and proposed buildings. This coordination should be considered in the location, configuration, and design of new buildings. Pedestrian ways should constitute natural extensions of building plazas, concourses, and public open space. They should connect major buildings with Metro stations and with each other, especially separate buildings of the same federal agency. New land use developments should be arranged to minimize travel distances, provide separate pedestrian movement channels, and allow for future micro-systems.

2. Transit, highway, pedestrian, and parking capacities should be commensurate with anticipated demands. The number of new free-standing off-street parking facilities probably will be limited; this reinforces the need to integrate Metro station access with circulation systems within buildings.

3. Home-to-work travel by Metro should be encouraged. This will call for (a) fast, frequent train service and (b) attractive pedestrian access and short walking distances between Metro stations and major buildings.

4. Walking times and distances should be minimized. This should be achieved through careful location and design of walkways and provision of complementary pedestrian assists or micro-systems where feasible.

5. Pedestrian ways should be safe, attractive, and convenient to use. Routes should be simple, direct, natural, and continuous. Pedestrians should be able to identify locations readily by particular visual features, such as signs and graphics along walkways. Directional signing should be clear and consistent. Safety and security should be maximized by means of light and open construction, ample sight lines, adequate illumination, and avoidance of concealed spaces. Suitable pedestrian environments should be provided through climate control and amenities such as benches, plantings, kiosks, and street furniture. A meaningful sequence of pedestrian spaces should relate to the area's

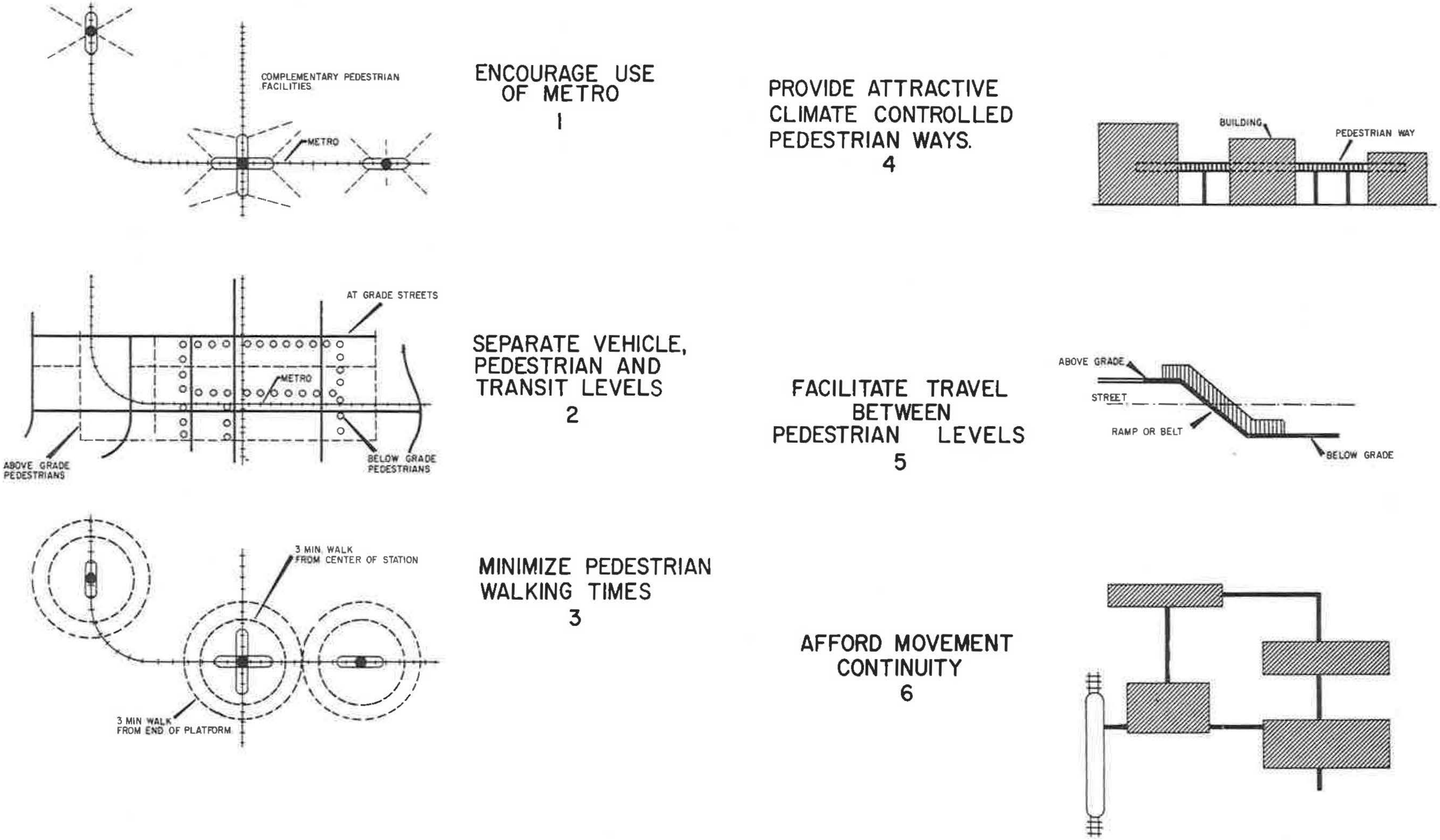


Figure 4. Pedestrian circulation concepts.

open space grid. Pedestrian ways should provide a minimum vertical headroom of 8 to 9 ft and a clear walking path 12 ft wide. Where moving ramps are included, additional width should be provided.

6. Pedestrian, vehicle, and transit movements should be separated. Vertical separation is especially desirable to minimize intersection conflicts because the opportunities for horizontal separation are limited.

7. Horizontal and vertical movement continuity should be provided. Pedestrians alighting from Metro trains below ground should be able to reach the 10th Street Mall and Promenade levels easily. It is desirable to facilitate travel between the various pedestrian levels through the use of escalators, ramps, elevators, and related devices. Stairs generally should be avoided because they are difficult to use. Uniformity of pedestrian levels should be maximized by avoiding or minimizing abrupt grade changes along major travel paths.

8. Pedestrian ways should adapt to the existing and future architectural setting. The adverse environmental impacts of skywalks and other pedestrian movement corridors should be minimized by (a) providing attractive design features that adapt and respond to basic architectural styles and values; (b) respecting major sight lines and vistas (this serves as a constraint on the number, location, and elevation of skywalks); and (c) constructing pedestrian ways through buildings, wherever feasible, because pedestrian ways through buildings do not require special supporting structures (Fig. 5).

9. Pedestrian ways should provide sufficient operational flexibility. Many key elements could operate independent of office or store hours; other links could operate only during daytime or peak hours.

10. Economical and realistic development of pedestrian ways should be achieved by (a) balancing investments in pedestrian facilities with demands; (b) utilizing, improving, and expanding existing movement corridors whenever possible; (c) coordinating development of walkways with building and Metro construction programs; (d) providing a high degree of locational flexibility to meet changing building plans and schedules; and (e) allowing for incremental expansion of the pedestrian movement system.

Concept Applications

These planning principles underscore the need for pedestrian movement continuity and for the vertical separation of pedestrian, vehicle, and transit movements.

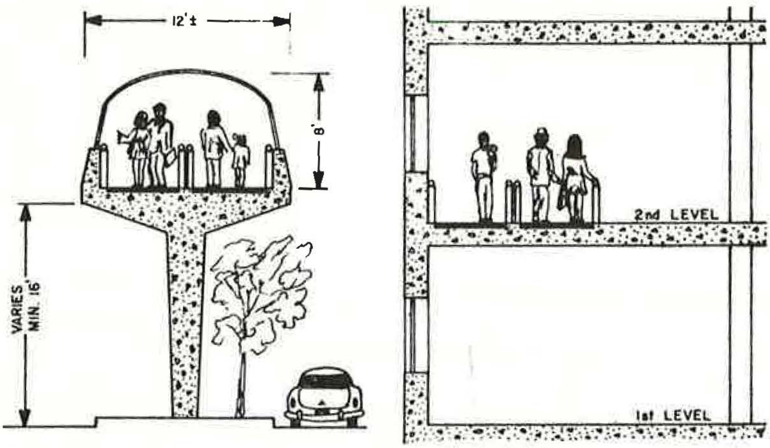
Vertical movement separation should include four basic circulation levels (Fig. 6):

1. The Metro level, the lowest level, includes station platforms and provides rapid transit service to the entire region;
2. The mezzanine level provides access to Metro trains and connects with major buildings;
3. The street or surface level continues to perform a variety of functions as the primary circulation level;
4. The plaza or pedestrian level interconnects buildings, malls, and plazas, generally above the street level.

The pedestrian circulation concept plan shown in Figure 7 spatially applies these principles. A grid of north-south and east-west skywalks is superimposed on the existing walkway system. It is complemented by a below-grade walk system that is closely coordinated with Metro station access. Pedestrian movement corridors penetrate buildings to maximize directness and continuity of movement.

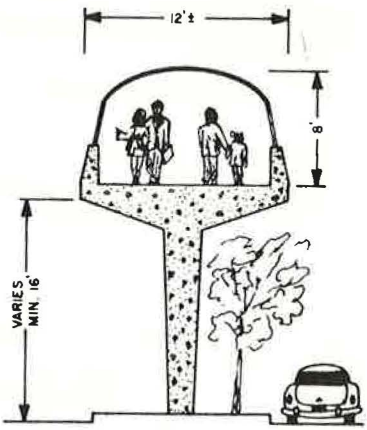
The integration of pedestrian circulation facilities with the Metro mezzanine level reflects long-established practice in New York City, Chicago, Philadelphia, Cleveland, Boston, and more recently in San Francisco, Toronto, and Montreal (e.g., the Rockefeller Center Concourse System in New York, Place Ville-Marie in Montreal, and the Market Street East Proposal in Philadelphia).

The concept plan was evaluated in terms of political, economic, and physical realities. Many existing buildings do not have the desire, design or collinearity features to incorporate pedestrian ways effectively. Metro station design proposals could inhibit effective coordination of mezzanine levels with the pedestrian circulation system (e.g.,



TYPICAL SECTION THROUGH ELEVATED MOVING SIDEWALK

TYPICAL SECTION THROUGH BUILDING



ELEVATED SIDEWALK

Figure 5. Skywalk design concept.

the open-arch type of station design and discontinuous mezzanines). Aesthetic considerations limit the location and extent of skywalk construction because the sight lines along Maryland Avenue and the Penn Central Railroad leading from the Capitol to the Jefferson Memorial must be respected. Finally, the plan must be balanced against developmental complexities and costs.

Accordingly, nine alternative plans were analyzed in the broad context of the area's near-term and long-range pedestrian transport and environmental needs. The plans ranged from minor adjustments in existing walkways to extensive underground and below-grade pedestrian movement systems. They included varying degrees of building penetration and use of micro-system (or people-mover) technologies.

Each plan was appraised in terms of its construction, service, environmental, and development implications. Factors included (a) extent of construction at, above, and below grade, over streets, and through buildings; (b) use of people-movers; (c) movement continuity; (d) number of buildings connected; (e) number of Metro stations directly served; (f) maximum travel time to subway stations; (g) relief afforded to major

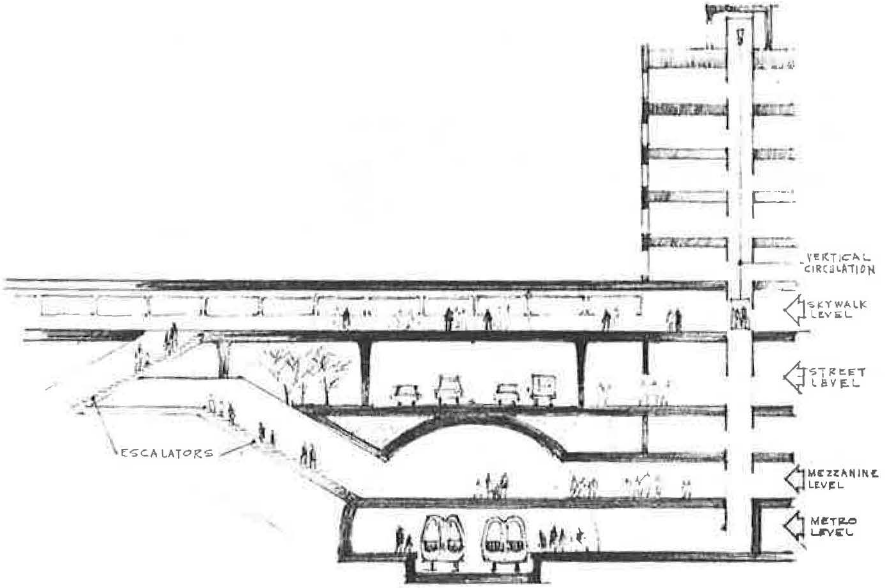


Figure 6. Vertical movement separation concepts.

sidewalks; (h) extent of all-weather pedestrian construction; (i) relative construction costs and complexity; (j) ease of operation; and (k) adaptation to stage construction. This comparative analysis provided a basis for developing the recommended pedestrian circulation plan.

The Plan

The recommended pedestrian circulation plan is shown in Figure 8. It is based on an ultimate employment of 100,000 persons and is designed to overcome existing pedestrian circulation deficiencies, meet future movement requirements, and provide an attractive pedestrian environment.

The plan serves the area's coordinated transport needs. Pedestrian ways improve access between the area and the metropolitan region and facilitate communication between activities within the area. The plan provides:

1. Climate-controlled pedestrian ways that are separated from vehicular traffic and are interconnected with major buildings;
2. Uniform elevations for principal pedestrian levels or subsystems;
3. Easy access between various pedestrian levels through the strategic use of escalators, ramps, and elevators;
4. Direct, conveniently located pedestrian ways between Metro stations and major buildings;
5. Full utilization of existing movement corridors wherever possible;
6. Pedestrian movement continuity from the Mall to the Maine Avenue waterfront;
7. Design compatibility of skywalks with their environs and with sight lines between the Capitol and the Jefferson Memorial;
8. Complementary moving belts, or micro-systems, to minimize pedestrian walking times, particularly over longer, uninterrupted segments of the system;
9. Opportunities for improved pedestrian amenities; and
10. Adaptability to extension and growth.

Major Elements—The plan includes approximately 2 miles of climate-controlled walks and 1,500 ft of strategically located moving belts (Tables 2 and 3). Proposed walkways are interconnected to existing pedestrian corridors to achieve a high degree of movement continuity and to reinforce the existing rectangular street grid.

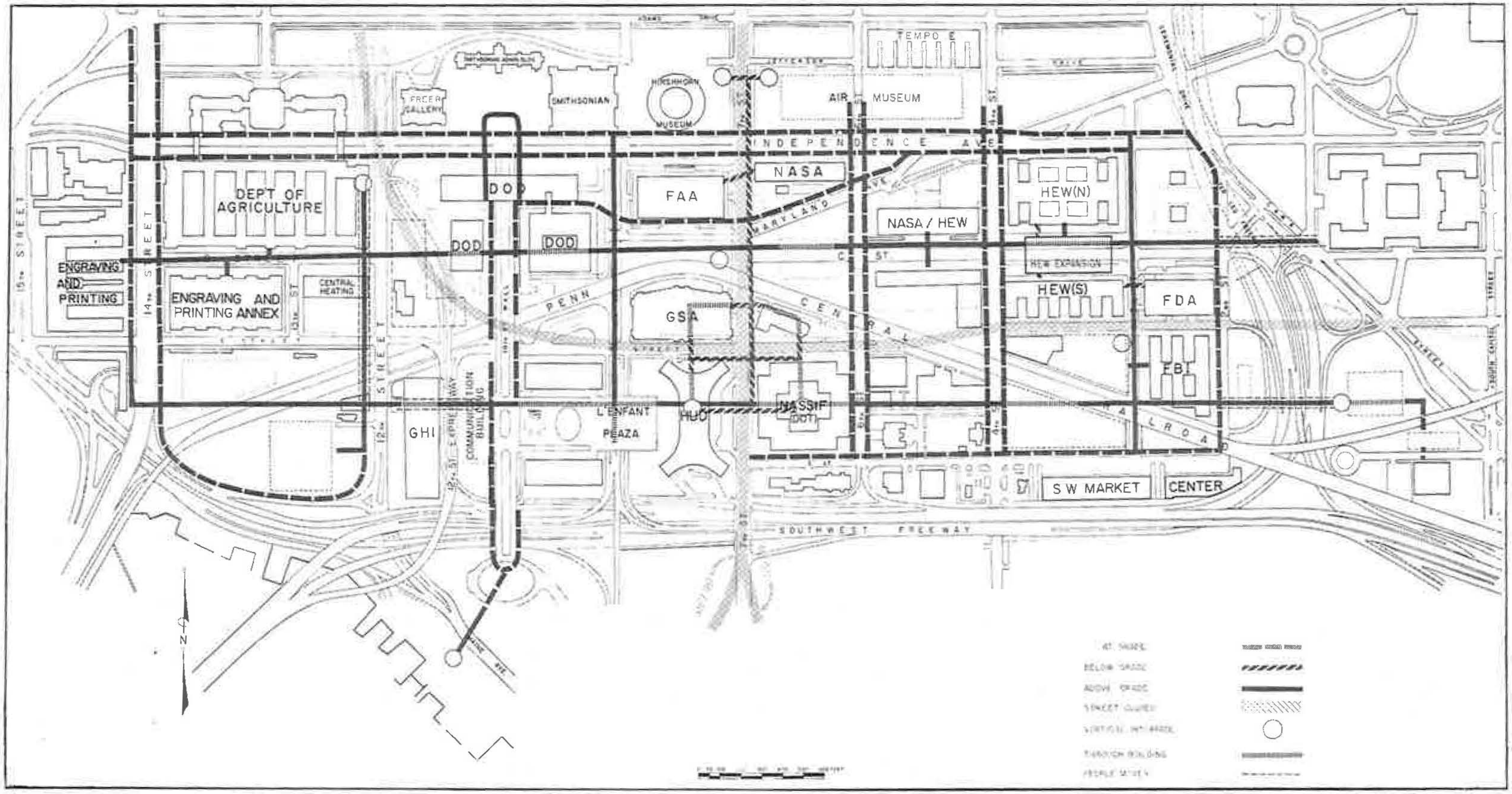


Figure 7. Pedestrian circulation concept plan, southwest employment area.

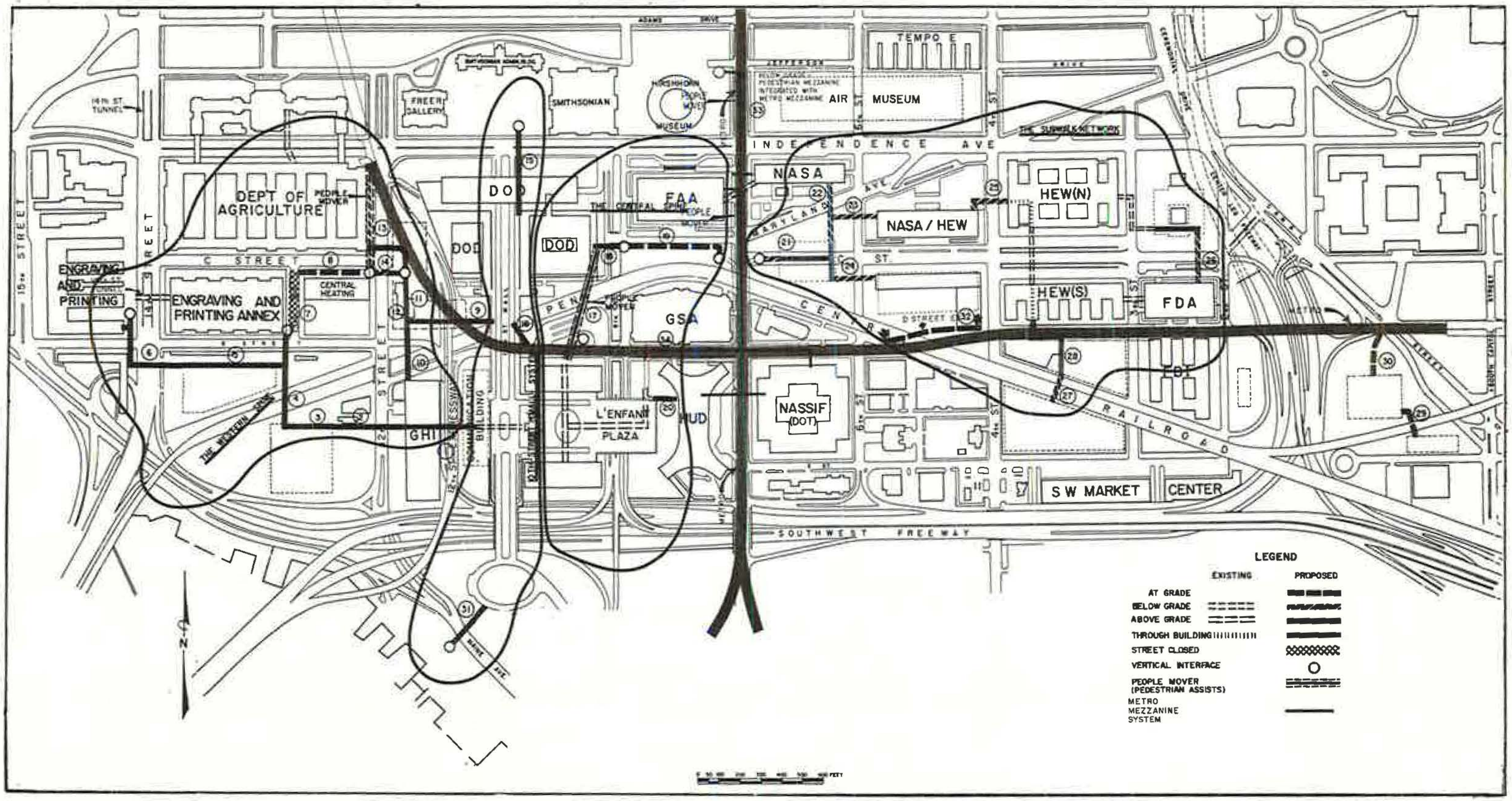


Figure 8. Pedestrian circulation plan, southwest employment area.

TABLE 2

MAJOR FEATURES—RECOMMENDED PEDESTRIAN CIRCULATION PLAN

Item	Description	Item	Description
1. Physical characteristics[a]		2. Service characteristics	
A. New walkways		A. Pedestrian movement continuity	Excellent
1. Elevated	3,350 ft	B. No. of buildings connected	36
2. At grade	1,800 ft	C. No. of Metro stations directly served	3
3. Street closure	300 ft	D. Maximum travel time to Metro station	4 min
4. Below grade	1,950 ft	E. Relief to major sidewalks	Excellent
5. Through buildings	2,000 ft	3. Environmental implications	
6. Metro mezzanine extension	1,000 ft	A. Extent of over-street construction	Minimal
Total	10,400 ft	B. All-weather pedestrian protection	Good
B. Pedestrian assists		C. Positive or negative effect	Positive
1. Elevated	400 ft	4. Developmental implications	
2. At grade	—	A. Cost factors	Moderate
3. Below grade	400 ft	B. Adaptability to stage construction	Yes
4. Metro mezzanine extension	700 ft	C. Coordination with Metro	Yes
Total	1,500 ft	D. Construction ease	Yes
		E. Operating problems	Minimal

[a] Excludes 1,000 ft of existing elevated walks and 1,000 ft of existing below-grade walks and mezzanine ways proposed by Metro.

TABLE 3

MAJOR NEW ELEMENTS—RECOMMENDED PEDESTRIAN CIRCULATION PLAN

Key Number	Description	Length (ft)							Priority
		Below Grade	At Grade	Street Closure	Above Grade	Metro Mezzanine Extension	Through Building	Pedestrian Assists	
1	GHI Skywalk	—	—	—	100	—	150	—	1
2	GHI-Portal Skywalk	—	—	—	300	—	—	—	4
3	Portal Ped-Way	—	—	—	—	—	250	—	4
4	13th Street Skywalk	—	—	—	450	—	—	—	4
5	North Portal Ped-Way	—	—	—	50	—	450	—	4
6	West D Skywalk	—	—	—	500	—	—	—	4
7	13th Street Walk	—	—	300	—	—	—	—	3
8	C Street Walk	—	350	—	—	—	—	—	3
9	9th St. Mall-Agriculture Skywalk	—	—	—	150	—	—	—	3
10	12th Street Skywalk	—	—	—	250	—	—	—	3
11	Agriculture Annex Ped-Way	—	—	—	—	—	500	—	3
12	C Street Subwalk	100	—	—	—	—	—	—	3
13	12th Street Subwalk	500	—	—	—	—	—	400	3
14	Agriculture Skywalk	—	—	—	100	—	—	—	3
15	10th Street Mall-Smithsonian Skywalk	—	—	—	300	—	—	—	1
16	10th Street Mall-D Street Ramp	—	—	—	100	—	—	—	1
17	9th Street Skywalk	—	—	—	500	—	—	400	1
18	C Street Skywalk	—	—	—	200	—	—	—	1
19	C Street Walk	—	600	—	—	—	—	—	1
20	HUD Skywalk	—	—	—	100	—	—	—	3
21	C Street Ped-Way and Subwalk	50	—	—	—	—	250	—	2
22	NASA-Sq. 493 Ped-Way and Subwalk	300	—	—	—	—	200	—	2
23	NASA Subwalk	200	—	—	—	—	—	—	2
24	Sq. 463-493 Subwalk	200	—	—	—	—	—	—	2
25	HEW Subwalk Extension	200	—	—	—	—	—	—	2
26	South Portal-FDA Subwalk	250	—	—	—	—	—	—	2
27	Sq. 537 Subwalk	150	—	—	—	—	—	—	4
28	Sq. 537-D Street Ped-Way	—	—	—	—	—	200	—	4
29	Community-Marfair Walk	—	150	—	—	—	—	—	4
30	Community-Canal Walk	—	200	—	—	—	—	—	4
31	Overlook Skywalk	—	—	—	250	—	—	—	1
32	D Street Extension Walk	—	500	—	—	—	—	—	4
33	7th Street Mezzanine Walk	—	—	—	—	1,000[a]	—	700	2[a]
34	D Street Mezzanine Walk	—	—	—	—	—[a]	—	—	2[a]
Total		1,950	1,800	300	3,350	1,000	2,000	1,500	

[a] Contingent on Metro construction. Distances indicate elements that are in addition to mezzanine planned by Metro.

The Western Spine—A new walkway system in the western part of the area links major buildings with the 12th and Independence Metro station and L'Enfant Plaza. The following principal elements are included (numbers in parentheses are keyed to Fig. 8):

1. The GHI-13th Street Portal-North Portal skyways (1-6) linking the Bureau of Printing and Engraving with L'Enfant Plaza;
2. The 13th and C Streets walkways (7, 8), an at-grade, climate-controlled walkway system that involves selected street closures and link the Portal Building complex with the 12th Street subwalk;
3. The 12th Street skywalk (10) connecting the GHI and the proposed Agriculture Annex Building;
4. The Agriculture Annex pedestrian way (12) that connects the 12th Street skywalk with the proposed Agriculture Annex Building extension; and
5. The 12th Street subwalk with moving belts (13), an underground pedestrian way linking the skywalk system and the Department of Agriculture complex with the Independence Avenue Metro station.

The 10th Street Mall System—Extensions of the 10th Street Mall walkways provide pedestrian movement continuity from the Mall to Maine Avenue. They include:

1. The 10th Street Mall-Smithsonian skywalk (15), an attractively designed extension across Independence Avenue into the Smithsonian complex area, and
2. The Overlook skywalk (31), a southerly, climate-controlled extension across Maine Avenue.

The Central Spine—A walk and skywalk system along 9th and C Streets links L'Enfant Plaza to the bus terminal, the Forrestal complex, the Federal Aviation Administration Building, and a proposed 7th and C Streets Metro entrance. It provides important pedestrian movement continuity through the heart of the area. This skywalk spine includes:

1. The 9th Street skywalk with moving belts (17), extending from L'Enfant Plaza to the plaza level of the Forrestal complex, and
2. The C Street walk and skywalk (18-19) connecting the Forrestal Complex and the proposed 7th and C Street Metro station entrance.

The Subwalk Network—This series of climate-controlled subsurface passageways (21-28) upgrades and extends the existing below-ground passageways in the Department of Health, Education and Welfare complex in the eastern part of the area. It links related buildings with the Voice of America and L'Enfant Plaza Metro stations.

Metro Mezzanine-Level System—This complementary, below-grade micro-movement system under 7th and D Streets (33-34) interconnects the Smithsonian Complex along the Mall, the Federal Aviation Agency, the General Services Administration Building, the Department of Transportation, the Department of Housing and Urban Development, and the L'Enfant Plaza Metro station. Short sections of moving belt are incorporated in extensions of the 7th Street mezzanine level to facilitate pedestrian movement. (Both the skywalk and subwalk pedestrian networks would, however, function as an integrated movement system if the proposed mezzanine extensions are not developed.)

Station Access Modifications—Several modifications in Metro station access are an essential part of the plan because most employees will use Metro. They include:

1. Provision for an underground connection from the Independence Avenue mezzanine to the proposed Department of Agriculture Annex Building extension;
2. An additional entrance in the northwest quadrant of the 7th and D Streets intersection, location on the west side of 7th Street at C Street and designed to permit east-west pedestrian crossings under 7th Street;
3. A new entrance to connect the HEW tunnel system with the Voice of America station;
4. Provision for a new entrance in the northeast quadrant of the 3rd and D intersection; and
5. Possible reorientation of the planned entrance at the 3rd and D intersection toward 4th Street.

Each proposed entrance point will be capable of serving at least 2,000 persons in the evening peak hour. This should more than meet anticipated needs for the area.

The revision of subway entrances from diagonally opposite sides of principal streets to reduce sidewalk congestion is common practice in other cities. The additional entrances will provide greater pedestrian routing options, complement the capacity of planned escalators, and reduce on-street pedestrian traffic at major intersections. Without additional entrances, serious sidewalk congestion could develop.

Transportation Service—The plan will effectively distribute pedestrian movements over existing and proposed walks. Most 1990 peak-hour flows will be less than 2,000 persons per hour (Fig. 9). Peak-hour volumes on proposed walkways will range from 500 to 2,500 persons per hour. The maximum volumes adjacent to the Independence and 12th and 3rd and D Metro entrances, 5,200 and 3,000 persons per hour respectively, will be substantially less than they would be without pedestrian circulation improvements or additional Metro entrances.

There will be significant reductions in peak-hour pedestrian loads in the currently congested core areas. For example, crosswalk volumes at the 7th and D Streets intersection would approximate 1,000 to 1,200 persons per hour in 1990 as compared with about 1,500 at present. Similarly, peak flows along 7th Street generally would be less than 1,000 persons per hour.

Development Priorities

Proposed pedestrian ways were estimated to cost about $2,500,000 at 1970 price levels, while costs for moving belts would add another $1,200,000. These order-of-magnitude cost estimates exclude costs for modifying the Metro mezzanine level or Metro entrance.

A four-stage construction program was developed (Fig. 10). Priorities reflect service afforded in relation to needs, building expansion plans, and relative ease of construction. The first stage includes the 9th and G Street and 10th Street Mall pedestrian ways to provide continuous pedestrian ways from Maine Avenue to the Mall and from L'Enfant Plaza to the D Street bus terminal and Forrestal and FAA buildings.

SEATTLE PEDESTRIAN WAY PEOPLE-MOVER PLAN

Seattle's 200-acre central business district contains 27 million sq ft of floor space and has an employment population of 60,000. Within the next decade, an additional 4 million sq ft of floor space and 8,000 employees are anticipated.

Movement Problems

The level of downtown congestion is not as acute as found in other CBDs of comparable size and intensity. This results in part from advanced planning and implementation of major transportation improvements. It also results from the unique setting of the center city. The city's shape, topography, and fragmentation by major water bodies such as Elliott Bay and Lake Washington place serious constraints on the number and capacity of transportation approach corridors; consequently, the major access problems are associated with line-haul movements to the center city.

Pedestrian circulation is the primary mobility problem within the downtown area. Grades on east-west streets ranging up to 16 percent constrain movements between the waterfront and the core area and inhibit more intensive development. Emphasis was placed, therefore, on developing an improved pedestrian circulation system within the broader context of a downtown transportation and land-use plan.

Surveys based on interviews with ferry passengers, parkers, and people entering major buildings identified pertinent pedestrian travel characteristics and provided the basis for deriving intra-CBD movement patterns between CBD zones for 1970 and 1980 (Fig. 11).

The Seattle central business district attracted nearly 100,000 persons from 7 a.m. to 7 p.m. on a typical 1970 day. Of these, 62 percent arrived by car, 27 percent by bus, 4 percent by ferry, 1 percent by monorail, and 6 percent as pedestrians. Once within

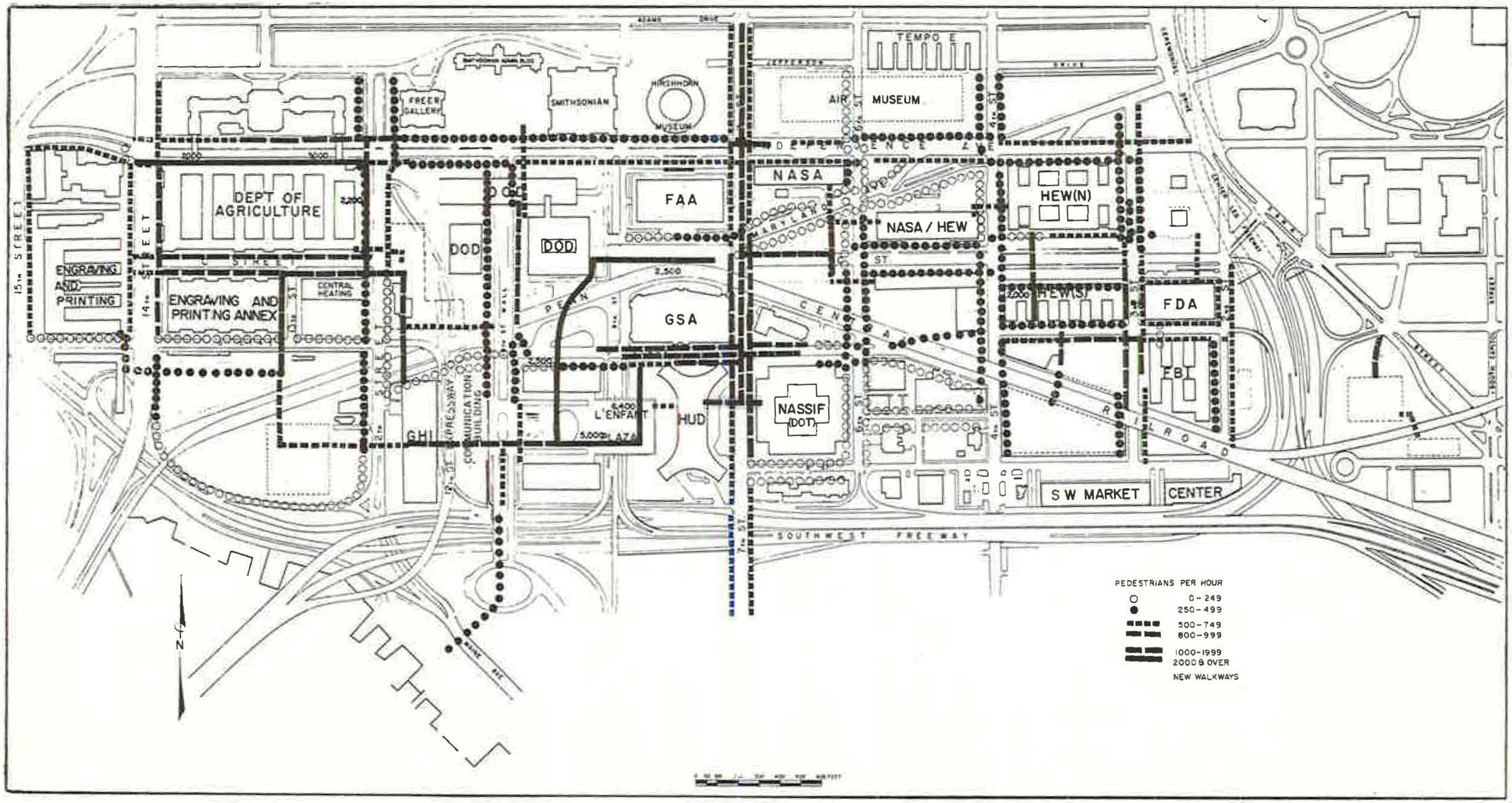


Figure 9. Anticipated 1990 p.m. peak-hour pedestrian volumes (recommended pedestrian circulation plan).

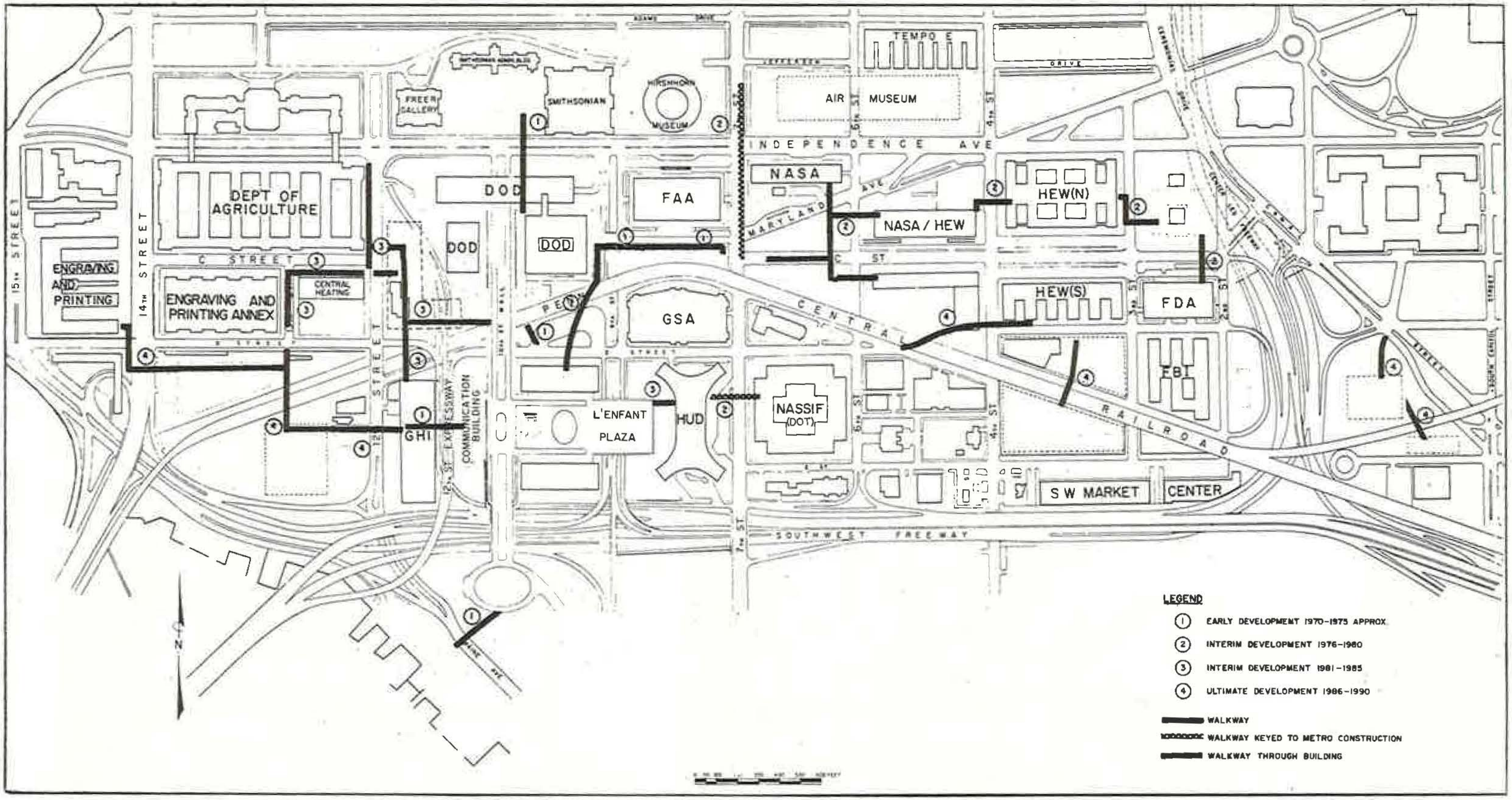


Figure 10. Construction priorities (recommended pedestrian circulation plan).

the downtown area, these people generated approximately 345,000 pedestrian trips. Nearly 60 percent (150,000) represented trips to or from bus stops or parking facilities; about 40 percent represented trips between buildings. Shopping trips accounted for approximately 31 percent of the total pedestrian trips, work trips 24 percent, personal business trips 17 percent, and commercial business trips 12 percent. The remaining 15 percent represented social-recreational, dining, and miscellaneous trips. Median

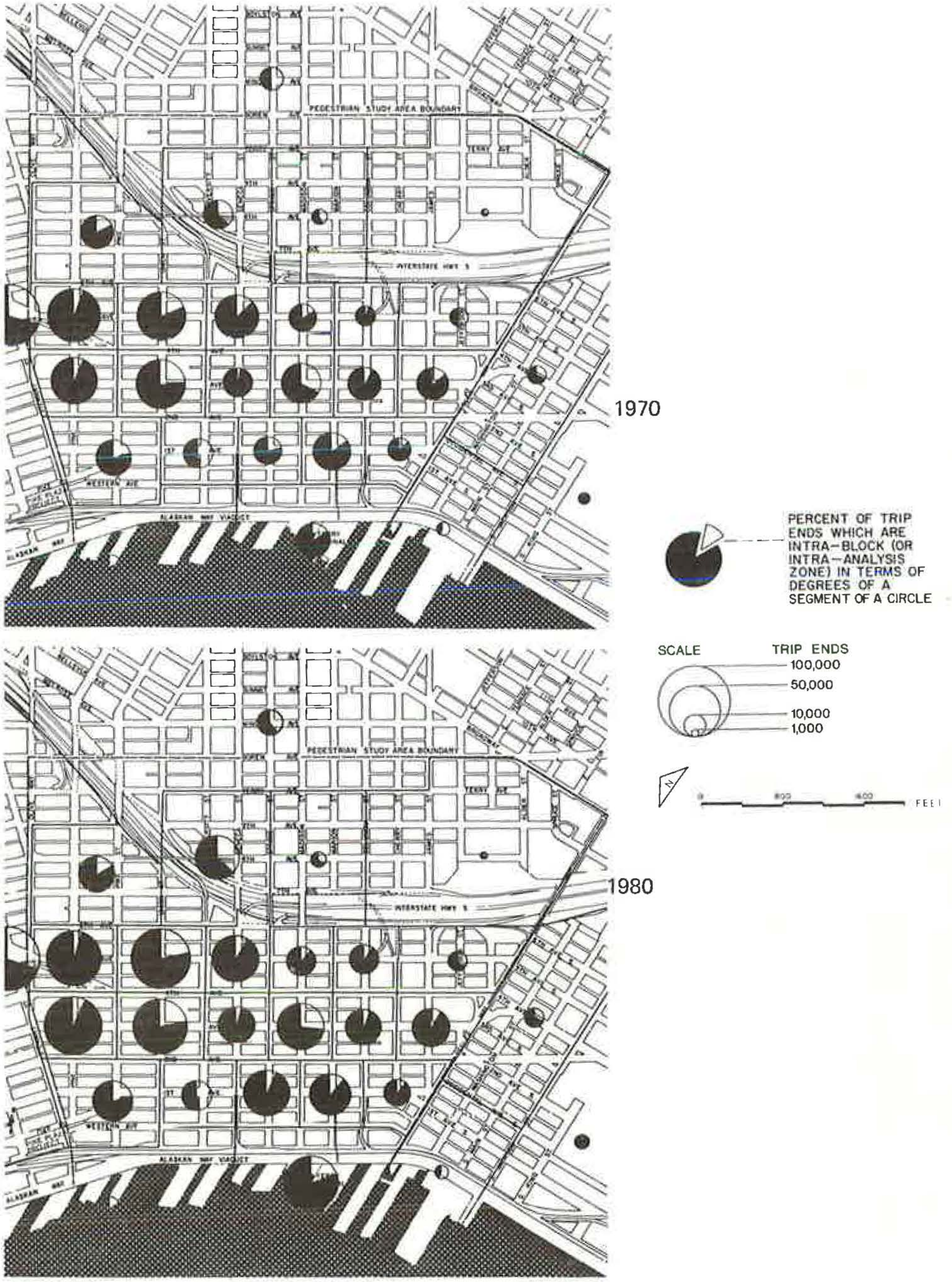


Figure 11. Seattle center pedestrian destinations, 7 a.m. to 7 p.m., 1970 and 1980.

walking distances were about 400 ft for trips between parking facilities and buildings and 700 ft for interbuilding trips.

Pedestrian Way Plan

An improved pedestrian circulation system that effectively links the waterfront and the core area would overcome the impediments of the steep grades and help catalyze new waterfront investments. Accordingly, the cost, patronage, service, environmental, and economic implications of an east-west people-mover system integrated with building access points and planned future walkways, parks, and redevelopment projects were evaluated.

Analysis of more than 100 potential people-mover technologies suggested a moving sidewalk system. The system could incorporate conventional moving belts and, perhaps, accelerated moving sidewalks when the technology becomes available. It could provide high service frequency, permit close station spacing, and penetrate or append buildings.

The Basic Concept

A people-mover route was analyzed along the general alignment of Madison Street, Third Avenue, and University Street (Fig. 12). It would connect the Ferry Terminal and a new 1,000-car garage at the waterfront with an expanded Federal Center, the Seattle First National Bank complex, the commercial core, and a new 500-car garage on First Hill. Ten stations would be strategically located along the mile-long route. Construction costs from $6 to $8 million were estimated at 1970 price levels.

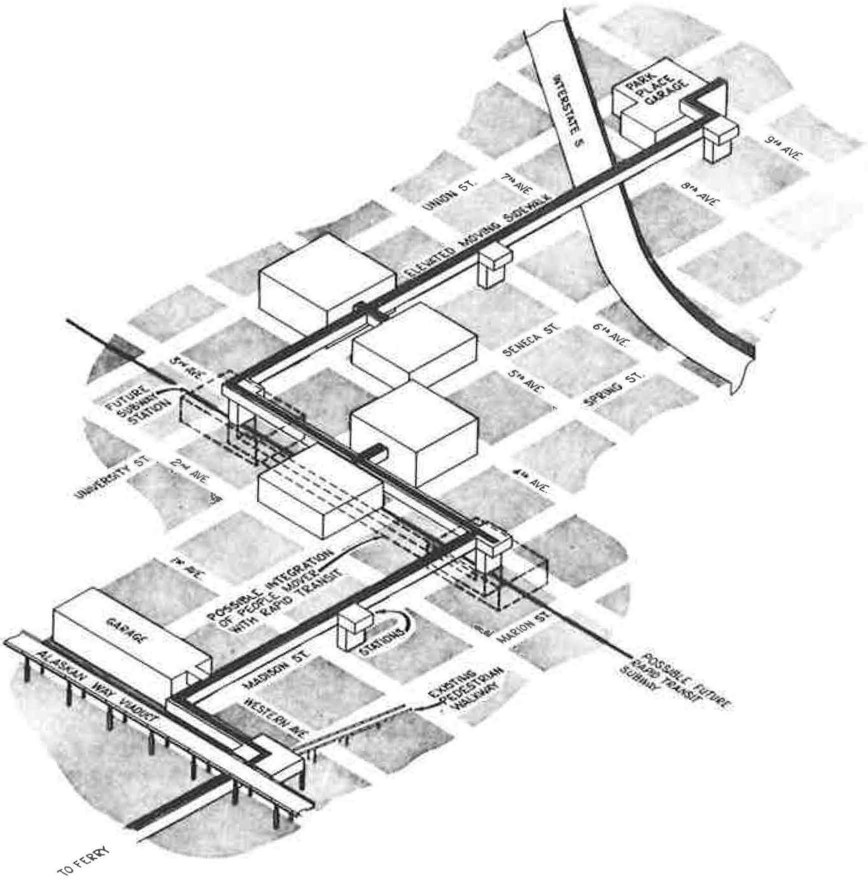


Figure 12. Seattle center city micro-system concept.

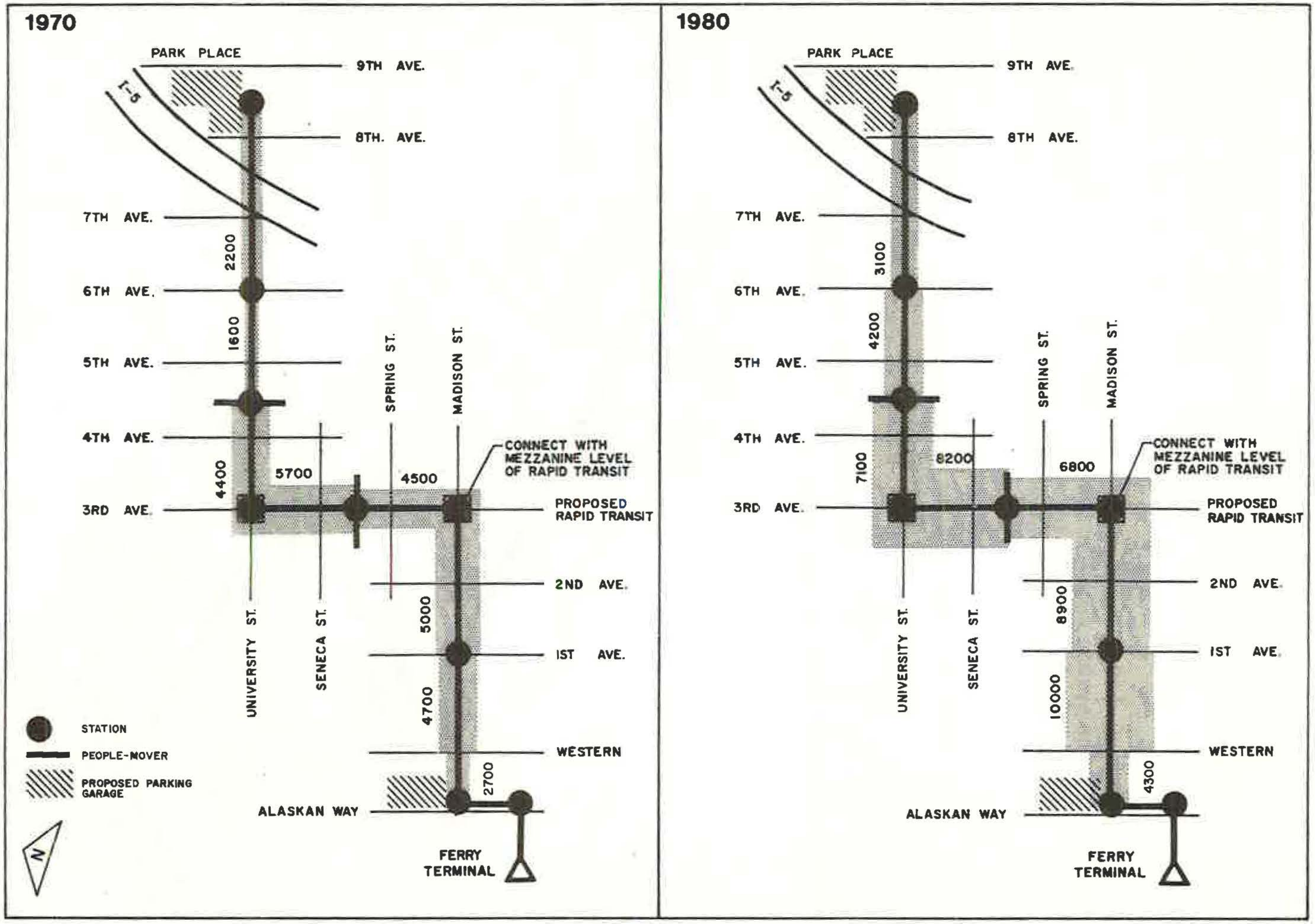


Figure 13. Anticipated 1970 and 1980 patronage, Seattle center city micro-system.

Pedestrian trip assignments were based on logical block-to-block movements within a 700-ft influence area. The system was estimated to serve about 13,000 persons per day at 1970 levels and 23,000 persons per day by 1980. These values represent 4 and 6 percent of the total 1970 and 1980 intra-CBD pedestrian trips respectively.

Estimated daily loadings would range from 1,600 to 5,700 persons based on 1970 levels and from 3,100 to 10,000 based on 1980 levels (Fig. 13).

The cost-patronage relationships indicate that the proposed people-mover system should be viewed primarily as a developmental catalyst. Its value will largely depend on the extent to which it can stimulate investment in its environs.

Early Action Plan

Emphasis should be placed on pedestrian way development with automation limited to key sections. The early action pedestrian way plan shown in Figure 14 reflects this objective. The plan provides continuous pedestrian circulation between the waterfront and the Olympic Hotel complex, through a combination of people-movers, skywalks, skybridges, and strategic use of internal building corridors. It extends the existing Sea-First pedestrian way to the immediate north, south, and east. This pedestrian way, in turn, is linked to the waterfront with an automated walkway along Madison Street. It allows for expansion as downtown redevelopment continues.

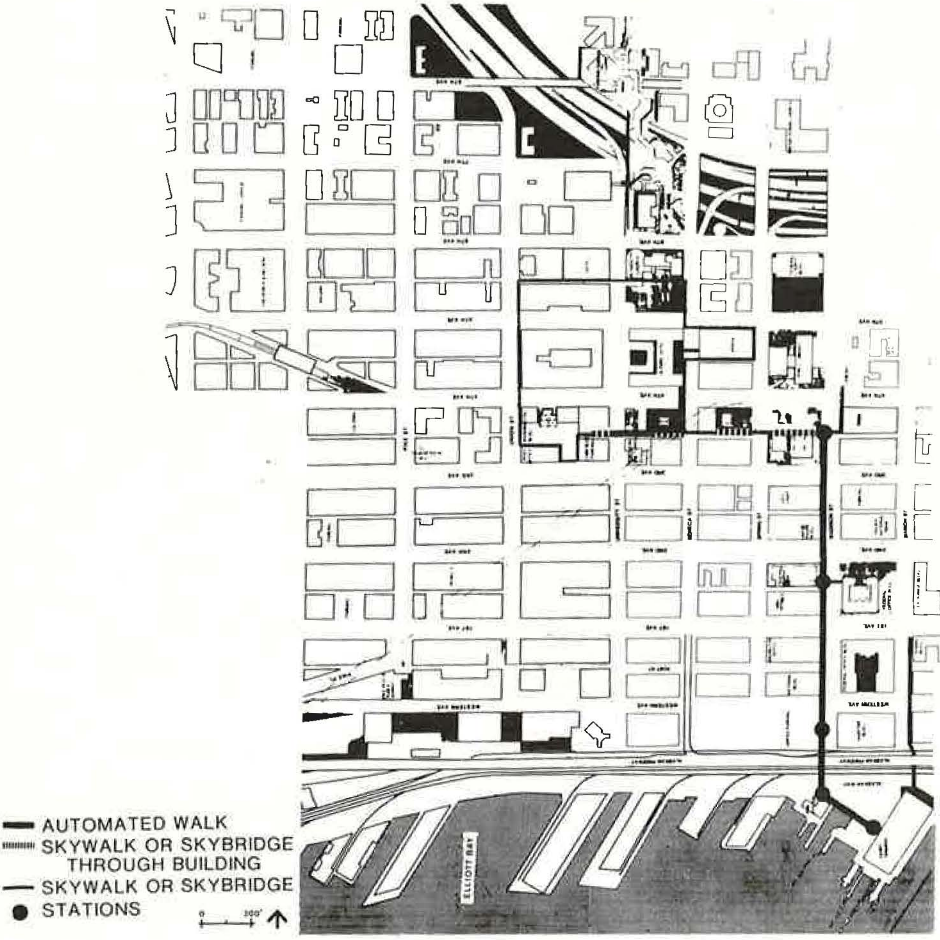


Figure 14. Suggested early action Seattle center city pedestrian way plan.

The plan gives priority to a moving sidewalk system along Marion and/or Madison Streets between the Ferry Terminal and Third Avenue. This link will (a) alleviate the adverse effects of the steep grade conditions between the waterfront and Third Avenue, (b) tie in with expanded peripheral parking along the Alaskan Way, (c) serve the existing captive market of Ferry travelers, (d) provide the greatest developmental impetus, (e) be the easiest to implement, and (f) achieve a reasonable balance between service and costs.

Minibus Option

A minibus service between the First Hill area and the Ferry Terminal, in conjunction with a short section of moving sidewalk at the Ferry Terminal, provides a suitable immediate-action east-west movement system (Fig. 15). This system could be

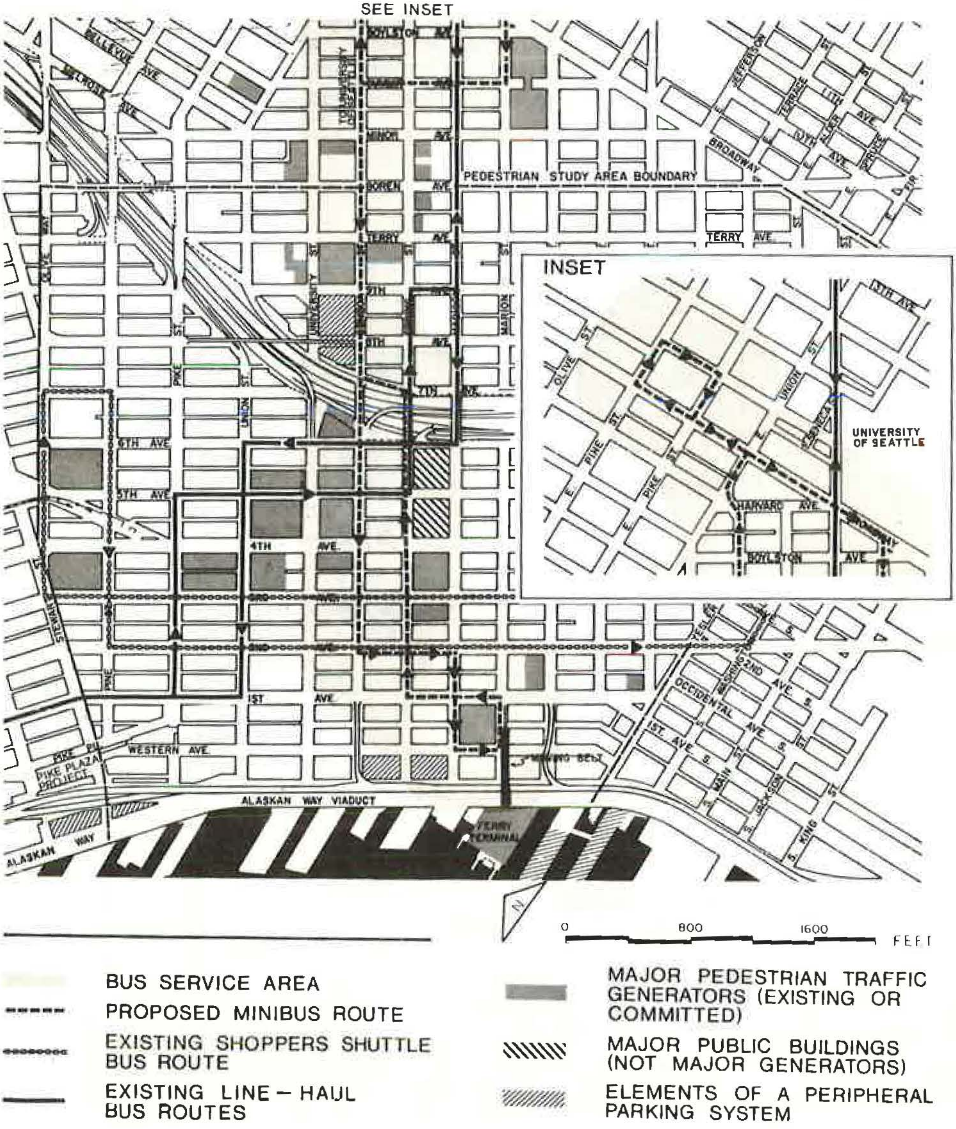


Figure 15. Early action plan for coordinated micro-system and shuttle bus service.

implemented within 6 to 12 months and used to establish customer patronage in advance of more complex and innovative systems.

CONCLUSIONS

The case studies suggest the following generalizations regarding pedestrian way planning and development:

1. There is need to provide pedestrian movement continuity and to separate pedestrian travel from vehicular movements.
2. The application of micro-systems should be selective within the broader context of overall downtown pedestrian way systems and regional transit services. The number of pedestrian corridors rather than the extent of automation should be maximized.
3. The preservation or advance acquisition of pedestrian movement channels should be encouraged. Pedestrian way plans provide an important framework for public and private investment decisions. Once plans are established, building codes and zoning ordinances could be modified to encourage redesign of existing buildings and design of new developments to incorporate or reserve pedestrian ways in conformity with the plan. A logical second step would be to install moving ramps in heavily traveled pedestrian concourses and escalator connections to ground floors of buildings. Ultimately, downtown buildings could adapt their main entrances to second-floor pedestrian ways.

Pedestrian movement systems are the logical means of extending the environments within individual building complexes into integrated networks. They call for commitment and coordination by participating federal, city, and private agencies through cooperative implementation programs. In this way, pedestrian circulation systems can optimize mobility and contribute to urban amenity as they transform major activity centers into efficient, interesting, and attractive pedestrian environments.

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