Pedestrian Speed-Flow Relationship for Central Business District Areas in Developing Countries

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Pedestrian speed-flow relationships for central business district (CBD) areas in developing countries were developed. Data were collected from Irbid, Jordan, which is considered a city typical of those in developing countries. In the analysis, pedestrian flows were analyzed on the basis of effective sidewalk width rather than the lane concept. Results indicate that the capacity of bidirectional CBD sidewalks was 18.22 pedestrians/min/ft (3,590 pedestrians/hr/m). On the basis of this result, the capacity value specified in the 1985 *Highway Capacity Manual* is not applicable to developing countries even if a reduction factor is applied to consider the bidirectional effect. In addition, the results indicate that a considerable percentage of pedestrians walk along streets beside sidewalks. Therefore, in the design of CBD sidewalks, it is recommended that the pedestrian demand to capacity ratio be limited to 0.5.

Most developing countries suffer from a lack of well-organized pedestrian facilities, and large cities in these countries expanded without suitable planning. The central business district (CBD) of any city encompasses most trading and local governmental activities. Because of the insufficiency of reasonable sidewalks, some pedestrians are forced to use the congested streets. This problem not only creates traffic delay and other adverse environmental effects but also can increase the probability of pedestrian and traffic accidents.

In Jordan, various measures have been taken either to control or to improve pedestrian flow. One of these measures is the fencing of sidewalks beside streets in the midblock strip. However, in spite of this action and media directions, some pedestrians jump over fences and flow into streets. Thus, fencing as a control measure is not effective, because the available sidewalks cannot accommodate pedestrian demand at an acceptable level of convenience. In an attempt to improve pedestrian flow and safety, some municipalities provided traffic-free areas. After the implementation, however, traders and business owners claimed that pedestrianization adversely affected their commercial life. Consequently, the time given to evaluate this kind of improvement was insufficient.

Thus, under these circumstances the only logical solution is to provide adequate sidewalks that can accommodate the expected demand at a reasonable level of convenience, safety, and economy. This can be achieved by widening the available sidewalks in the CBDs. To do so, speed-flow and speed-space relationships must be developed. These relationships are readily available in the *Highway Capacity Manual* (*1*). They were developed through studies carried out in some developed countries under certain spatial, temporal, and pedestrian preferences. Therefore, there is a need to develop the basic relationships for the flow of pedestrians in developing countries similar to Jordan.

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PURPOSE AND SCOPE OF RESEARCH

The primary purpose of this research is to study and develop the basic relationships for CBD pedestrian sidewalks in Jordan. The secondary purpose is to compare the results of this study with those developed in previous research in the developed countries.

The scope of this research is limited in two ways. First, mixed pedestrian traffic was considered, because it is very difficult in the CBD to classify pedestrians according to trip purpose. Second, in the CBD, the directional distribution of pedestrians changes in a short time. Therefore, bidirectional flow was considered in this study.

The study was conducted in Irbid's CBD. Irbid is located in the northern part of Jordan and can be considered typical of cities in developing countries. Irbid has a population of 250,000. The city is the business center of Irbid Governorate, which has a population of about 750,000.

STUDY METHODOLOGY

Three criteria were adopted at the commencement of the study. First, the developed speed-flow relationship must be based on short-time variation of pedestrian flow. Second, the selected time period must be sufficient to take reasonable measurements according to available measurement techniques. Third, to assess the relative degree of convenience, both pedestrian preferences and engineering judgment must be considered. On the basis of these criteria, the following procedure was followed:

1. A manual technique was used to collect pedestrian traffic flow and speed data. Pedestrian flow and speed measurements were carried out by two observers equipped with stopwatches. Observers were positioned outside the sidewalk. One ob-

server counted the number of pedestrians that passed a line of sight across the width of the sidewalk during a specified period of time. The other measured the time required by randomly selected representative pedestrians to traverse a specific length of the sidewalk during the same specified period of time. The pedestrian flow rate was computed as the number of pedestrians per minute per foot of effective sidewalk width. The effective width was determined according to 1985 *Highway Capacity Manual* practice. Pedestrian speed was computed as the average pedestrian walking speed (ft/min).

During the initial phase of the study, it was noted that platoon patterns occurred during midday (11 a.m. to 2 p.m.). Thus, the study of short-term variations of pedestrian flow was carried out at 1-min intervals. Since a 1-min interval is not practical for speed measurements, a relationship between 1-min flow and average flow for longer periods of time, such as 5-, 10-, and 15-min intervals, is necessary to develop speed-flow relationships.

2. To assess the degree of convenience, three pieces of information were collected at each flow level. The information included the degree of convenience as judged by pedestrians, the degree of convenience as judged by an engineer, and the percentage of pedestrians walking along the street beside the sidewalk. Three observers working simultaneously were used to collect this information. Pedestrian flow was determined by the first. A number of pedestrians were selected randomly to give their judgment on a short questionnaire form distributed by the second observer. Since pedestrians do not know the meaning of a given level of service as A, B, . . ., or F, they were asked to judge whether the sidewalk over a specified length could be classified, from an operational perspective, as excellent (A), very good (B), good (C), fair (D), accepted (E), or unaccepted (F). The percentage of pedestrians walking along the street was estimated by the third observer.

STUDY AREA AND DATA COLLECTION

To achieve the objectives of this research, a major part of the Irbid CBD was selected. The selected part has an area of 75,000 m^2 and total street length of 2,500 m. The streets approximate a grid system with dimensions 80 × 120 m. Sidewalks are provided on both sides of each street. The sidewalks have widths ranging from 1.5 m (5 ft) to 2.4 m (8 ft). The selected sidewalks were considered to be in good condition. The study was conducted between the beginning of April and the end of July 1991.

Two major data sets were collected. The purpose of the first was to study the temporal variations of pedestrian flow. To determine peak flow periods, two sidewalk sites were monitored continuously during a week from 6:30 a.m. to 6:30 p.m. Pedestrian flows were recorded at 5-min intervals. In addition, six sidewalk sites were monitored continuously for 3 hr at different time periods. At each site, pedestrian flows were recorded at 1-min intervals.

The second data set was collected to develop speed-flow relationships and space requirements for CBD pedestrian traffic. The data were collected from six sidewalks. At each site, pedestrian flows were recorded continuously at 5-min intervals for 3 hr. Within 5-min intervals, average speed was computed as the mean of individual pedestrians' speeds. However, under low-flow conditions some observations were collected at 1-min intervals, and a few pedestrians were randomly selected to compute the average speed. Pedestrians' speeds were determined by measurement of the time required to traverse a referenced section of sidewalk 30 ft long. The length was determined so that the effective width of the sidewalk is constant.

To assess the relative degree of convenience and to quantify the adequacy of the available sidewalks, a supplementary data set was collected. It included two questionnaire forms, which were distributed at the same time in the field, one answered by a pedestrian and the other by an engineer. In each 5-min interval, three pedestrians who traversed the section under consideration were randomly selected to give their responses. In addition, the percentages of pedestrians walking along the street beside the sidewalk were computed at 5-min intervals.

DATA ANALYSIS AND RESULTS

Data were analyzed by using the Statistical Analysis System (SAS) computer package.

Temporal Variation of Pedestrian Flow

Figure 1 shows variations of pedestrian flow at one of the selected sites from 6:30 a.m. to 6:30 p.m. The peak pedestrian flow occurred from 11:00 a.m. to 1:00 p.m. Platoon flows were noted in the field. Therefore, speed-flow relationships for planning and design purposes should be developed on the basis of short time intervals. However, 1-min intervals were not sufficient to take a reasonable number of speed measurements. Thus, the first data set was used to develop the relationship between 1-min flow and the average flow in longer intervals.

The relationship between the maximum 1-min flow (F1) within a 5-min interval and the average 5-min flow (F5) was investigated. Regression analysis indicated that the relationship was linear with an r^2 value of 0.99. The resulting equation is

$$F1 = 3.535 + F5 \tag{1}$$

The relationship between the maximum 1-min flow (F1) within a 10-min interval and the average 10-min flow (F10) was linear with an r^2 value of 0.98. The resulting equation is

$$F1 = 3.764 + 1.015F10 \tag{2}$$

Also, the relationship between the maximum 1-min flow (F1) within a 15-min interval and the average 15-min flow (F15) was investigated. A linear regression model provided the best fit with an r^2 value of 0.96. The equation obtained is

$$F1 = 4.104 + 1.014F15 \tag{3}$$

Investigation of residuals in all previous models indicated that variances were consistent, but they increased with the increase in the average flow interval. In addition, no outliers

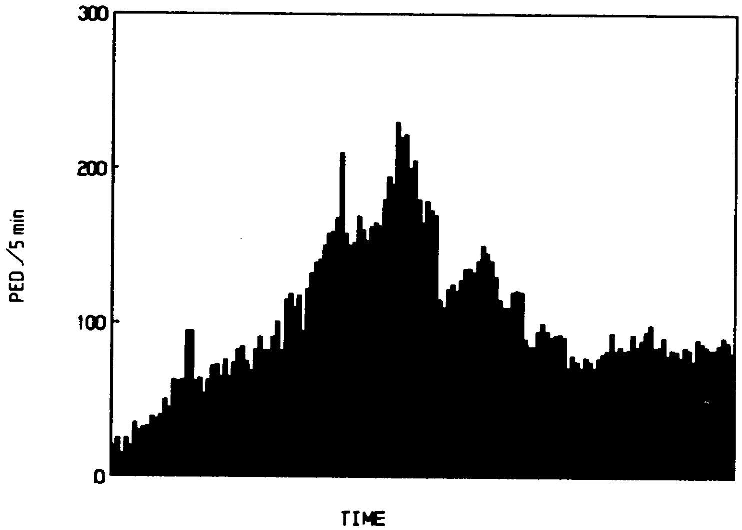

FIGURE 1 Pedestrian flow by 5-min intervals in Irbid (6:30 a.m. to 6:30 p.m.).

were detected if the average flow is more than 2 pedestrians/min/ft. Therefore, the previous relationships can be considered valid for average flows of more than 2 pedestrian/min/ft, as shown in Figure 2.

In conclusion, the maximum 1-min flow can be estimated from the average of 5-, 10-, and 15-min flows. The 5-min interval is characterized by lower variance and a higher coefficient of determination. Moreover, the 5-min interval provided ample time to take reasonable speed measurements based on manual techniques.

Development of Speed-Flow Relationship

The second data set was used to develop the speed-flow relationship. For flows in excess of 2 pedestrians/min/ft, flows

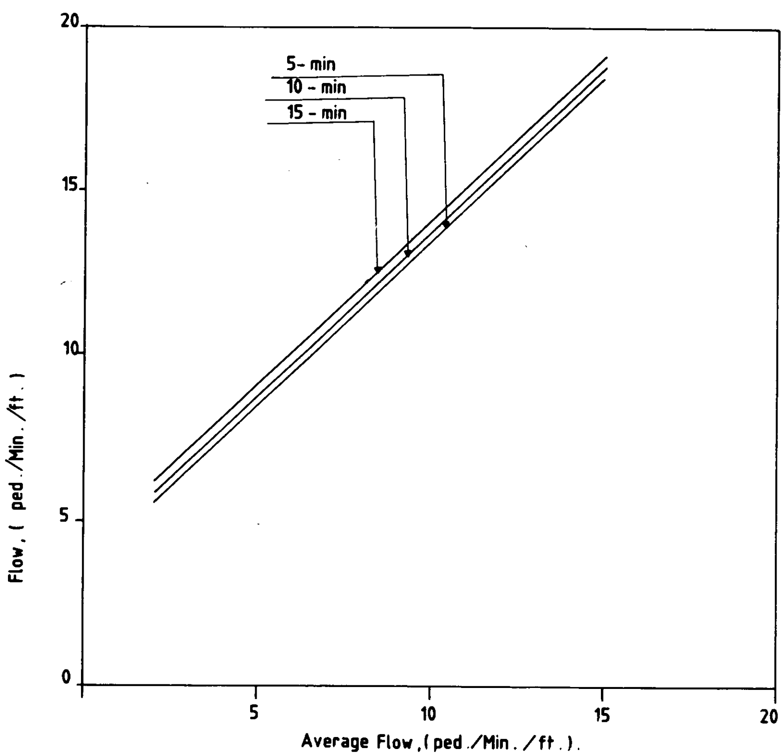

FIGURE 2 Relationship between maximum 1-min flow and the average of 5-, 10-, and 15-min flows.

were adjusted to reflect the maximum flow according to Equation 1. For low pedestrian flows, speed and flow collected at 1-min intervals were used. The following polynomial regression provided the best fit:

$$F = 5.816 + 0.1903S - 7.3 \times 10^{-4}S^2 \quad (4)$$

where F is flow (pedestrians/min/ft) and S is average speed (ft/min). Results of the statistical model are given in Table 1.

The speed-flow relationship is shown in Figure 3. The free-flow speed was 288 ft/min (1.463 m/sec), speed at maximum flow was 131 ft/min (0.665 m/sec), and the maximum flow (capacity) was 18.22 pedestrians/min/ft (3,590 pedestrians/hr/m). The speed-space relationship is shown in Figure 4. The minimum space requirement was 5 ft^2 per pedestrian, and the average speed was almost constant if the space exceeded 120 ft^2 per pedestrian.

Evaluation of Relative Degree of Convenience

Analysis of data collected to evaluate the relative degree of convenience as a function of flow level indicated that the correlation between pedestrian response and engineering judgment was very low. This may be because engineering judgment was based on the available space per pedestrian and possibility of conflict within the selected sidewalk section, whereas pedestrian judgments might be affected by walking conditions throughout the trip rather than the specified section. For the most part, pedestrians underevaluated the relative degree of convenience.

The percentage of pedestrians walking along the street beside a sidewalk was analyzed as a function of flow level. The relationship between the percentage of pedestrians walking along the street beside a sidewalk and the demand flow as a ratio from capacity (18.22 pedestrians/min/ft) is shown in Figure 5. The results indicate that, even at low demand to capacity (V/C) ratios, there was a considerable percentage of pedestrians walking along streets. Also, it is clear that up to V/C equal to 0.5 the percentage of pedestrians walking along streets was below 5 percent, but for V/C more than 0.5 the percentages increased substantially.

DISCUSSION OF RESULTS

In this study, the manual technique was adopted because other techniques such as photography and videocamera are either

TABLE 1 Analysis of Variance and Estimate of Parameters for Speed-Flow Relationship

Source	DF	Sum of Squares	Mean Square	F-Value	Prob >F
Model	2	6281.357	3140.678	1472.040	0.0001
Error	237	505.653	2.134		
Total	239	6787.010			

Adjusted R-Square = 0.925

Variable	DF	Parameters Estimates: Parameter Estimate	Standard Error	T for Ho: Parameter = 0	Prob>|T|
Intercep	1	5. 816	1.5209	3.824	0.0002
Speed	1	0.1903	0.0164	11.621	0.0001
Speed-Square	1	$-7.3*10^{-4}$	$4.1*10^{-5}$	-17.711	0. 001

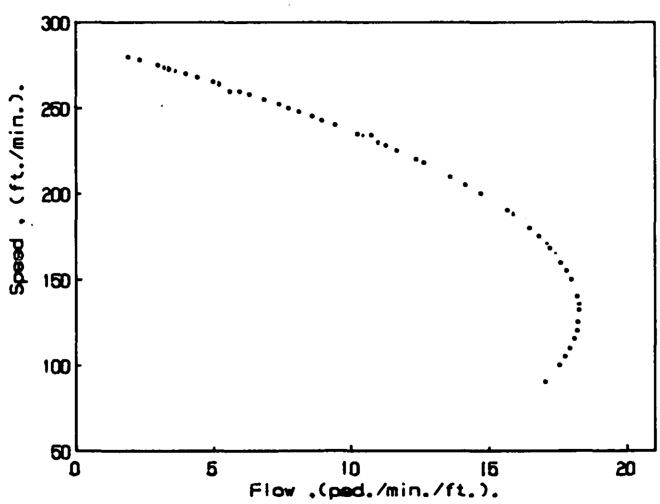

FIGURE 3 Pedestrian speed-flow relationship for CBD.

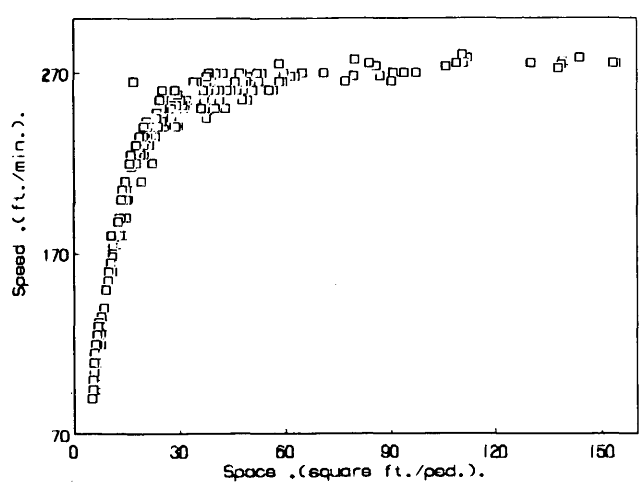

FIGURE 4 Pedestrian speed-space relationship for CBD.

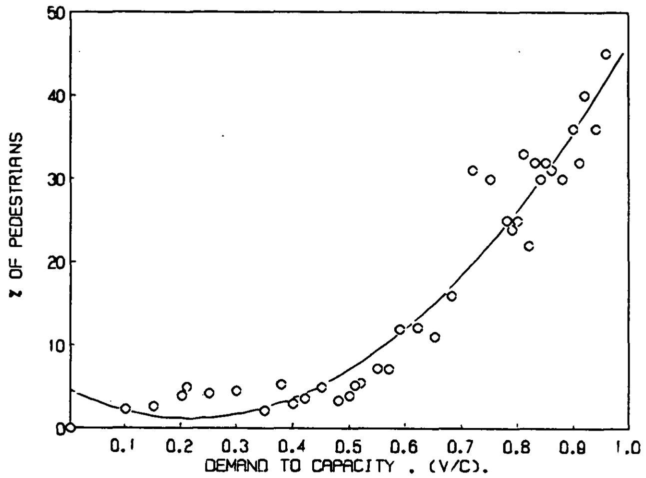

FIGURE 5 Relationship between percentage of pedestrians walking along streets and demand to capacity ratio.

very expensive or not validated for wide use (e.g., image analysis) (*2*). The manual technique is widely used, and any inherent uncertainties or inaccuracies in time and speed measurements due to human reaction time can be ignored for practical purposes. Pedestrian flows were analyzed on the basis of effective sidewalk width rather than the lane concept. The use of the lane concept is only reasonable under certain conditions, such as pedestrian arrival corridors (*3*).

Analysis of pedestrian flow variations in the CBD indicated that peak flow occurred from 11 a.m. to 1 p.m. This period is expected since most employers, workers, and schools terminate their working day. Because of inhomogeneity of trip purposes, platoon patterns were noted in this period. Thus, to take into account these patterns, a 1-min interval was adopted as a basis for flow study. Results of temporal variation of pedestrian flow indicated that maximum 1-min flow can be estimated from average flows of 5-, 10-, and 15-min intervals by using additive adjustment factors. However, the results indicated that the use of average 5-min flow to estimate maximum 1-min flow was more accurate than other intervals. According to the 1985 *Highway Capacity Manual*, if flow is more than 0.5 pedestrian/min/ft, platoon flow can be estimated from 15-min flow by using an additive adjustment factor of equal to 4.0 (*4,5*). In this study, it was found that if the flow is more than 2 pedestrians/min/ft, the corresponding factor will be 4.10. The discrepancy in the range from 0.5 to 2 pedestrians/min/ft is probably because platooning formation was only noted in the CBD at higher levels of flow.

The estimated capacity of the CBD sidewalks as shown in Figure 3 was 18.22 pedestrians/min/ft (3,590 pedestrians/hr/m). This value is very low compared with the 25 pedestrians/min/ft specified in the 1985 *Highway Capacity Manual*. The reduction in capacity was about 25 percent. One reason for this reduction is that in this study bidirectional flow was considered. Pushkarev and Zupan (*5*) pointed that a maximum reduction of 14.6 percent is possible if the ratio of opposing flows is 90:10. However, the results of this study are similar to the result of two-way passageways for London underground stations (*6*), 18.92 pedestrians/min/ft (3,725 pedestrians/hr/m). Pedestrian behavior may be attributed to other reasons: presence of luggage-laden pedestrians and density of shops in the CBD. Free-flow speed and speed at capacity obtained in this study are comparable with the values cited in the *Highway Capacity Manual* and passageways of London underground stations.

The survey of the relative degree of convenience based on evaluations by pedestrians and engineers did not provide adequate results. As mentioned earlier, pedestrians under-evaluated the relative degree of convenience, and their judgments at the same level of flow were widely inconsistent. The inconsistency may be explained by the following factors: (*a*) pedestrians having different trip purposes gave different judgments specifically at higher levels of flow; (*b*) apparently, pedestrians gave their judgments about sidewalks in general rather than the specified sidewalk section; and (*c*) differences in education, age, and other factors might affect pedestrian evaluations.

The last measure used to evaluate the relative degree of convenience as well as pedestrian safety was the percentage of pedestrians walking along a street beside a sidewalk as a function of flow level. The result indicated that, up to V/C equal to 0.5, the percentage of pedestrians walking along the street was about 5 percent. For higher values of V/C, percentages increased substantially, probably because commuter pedestrians were seeking a higher level of service in terms of speed. For V/C less than 0.5, the percentage of pedestrians walking along a street was very low and can be reduced or eliminated through education and enforcement. For higher values of V/C it is clear that the increase was very high and cannot be afforded easily. Therefore, in the planning and design of CBD sidewalks, it is recommended that V/C be limited to 0.5. In addition, a study of accidents in the selected area indicated that pedestrian accidents were 23 percent of the total traffic accidents, and 45 percent of pedestrian accidents happened to pedestrians walking along streets. For pedestrians walking along streets, the study indicated that 60 percent of the relevant accidents occurred between 1 and 2 p.m. Thus, a period of high pedestrian demand associated with insufficient sidewalk width and a low degree of convenience was characterized by high pedestrian accidents.

CONCLUSIONS AND RECOMMENDATIONS

Studies of temporal variation of pedestrian flows and speed-flow relationships for CBD sidewalks were undertaken. The results of the studies led to the following conclusions:

1. The best pedestrian counting interval to estimate maximum 1-min pedestrian flow was the 5-min interval.
2. The capacity of a bidirectional CBD sidewalk was 18.22 pedestrians/min/ft (3,590 pedestrians/hr/m).
3. The speed-flow relationship developed in the 1985 *Highway Capacity Manual* overestimates the capacity of CBD sidewalks in developing countries even if a reduction factor is applied to consider the opposing flow.
4. A considerable percentage of pedestrians walk along streets even at low flow levels. Consequently, education and enforcement are needed.
5. In the design of new sidewalks or improvement of existing CBD sidewalks, it is recommended that the demand to capacity ratio be limited to 0.5.

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