model produced good results in a short time and fulfilled the needs of the designers.

On balance, the model documented here provided many of the advantages of more sophisticated pedestrian simulation models while offering added flexibility of analysis, simplicity of spreadsheet programming, and quick response associated with personal computing. It is expected that the software and methodology described here will be refined and used on further projects.

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Application of the Time-Space Concept to a Transportation Terminal Waiting and Circulation Area

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ABSTRACT

Demonstrated in this paper is the application of the time-space concept to the analysis of pedestrian activities in the waiting and circulation area of a transportation terminal. It is intended to show how this approach can address situations and problems not adequately handled by the use of other methods. The time-space concept is described first. It is a new procedure for analyzing pedestrian activities (especially those associated with transportation facilities and dense urban centers) in which the following factors are taken into account: (a) the total amount of space required for the various activities of people within an area, (b) the amount of time they require that space, (c) the amount of available space, and (d) the amount of time that space is available. Following the discussion of the time-space concept, a case study is presented to demonstrate some of its capabilities and features. The problem is analyzed first by using the traditional flow rate approach and second by using the new time-space method. Finally, the two analyses are compared and the situations in which the new approach would be advantageous are pointed out.

The time-space concept is a new approach to analyzing and evaluating facilities for handling pedestrian activities, especially those associated with transportation terminals, transit stations, and dense urban centers. The time-space concept, first introduced as a method for examining sidewalk corners and crosswalks (1-2), can be applied to any facility where pedestrian activities--walking, waiting or queuing, and processing--occur. This approach can address many situations and problems that cannot be adequately addressed using other methods.

Basically, the time-space concept considers the total amount of space required by the people involved in various activities within an area, and the amount of time that they require that space. At the same time, it considers the amount of space available for these activities and the amount of time that the space is available.

Demonstrated in this paper is the application of the time-space concept to the analysis of pedestrian activities within a proposed facility for a transportation terminal. The time-space concept is described first. Then, a case study is presented that demonstrates some of the capabilities and features of the time-space concept. The same problem is analyzed using the more traditional flow rate technique and the two approaches are compared.

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PEDESTRIAN PLANNING AND DESIGN FUNDAMENTALS

Most of the material presented here is based on three sources (2-4). It is readily recognized that people

require certain and varying amounts of space for different activities and that the amount of space available affects a person's performance and comfort level. A person waiting on a platform requires a minimum of 7 ft^2 of space, but prefers and needs approximately 10 to 13 ft^2 to remain comfortable for any length of time. About 25 ft^2 of space per person is the threshold of "free flow," where someone can walk as fast as desired with reduced chances of interference from or conflict with other pedestrians. As the area per person decreases, the chance of conflicts with other pedestrians increases and the speed at which the person can walk is reduced. When the area per person decreases to 7 ft^2, walk speeds are typically reduced to 140 to 150 ft/min, about one-half the free-flow norm.

This relationship between walk speed and space per person has been demonstrated by Fruin (3) and others (4) who established the relationships of area per person to walking speed and flow volume (passengers per minute per foot width). (See Figures 1 and 2.) Level-of-service standards were defined, ranging

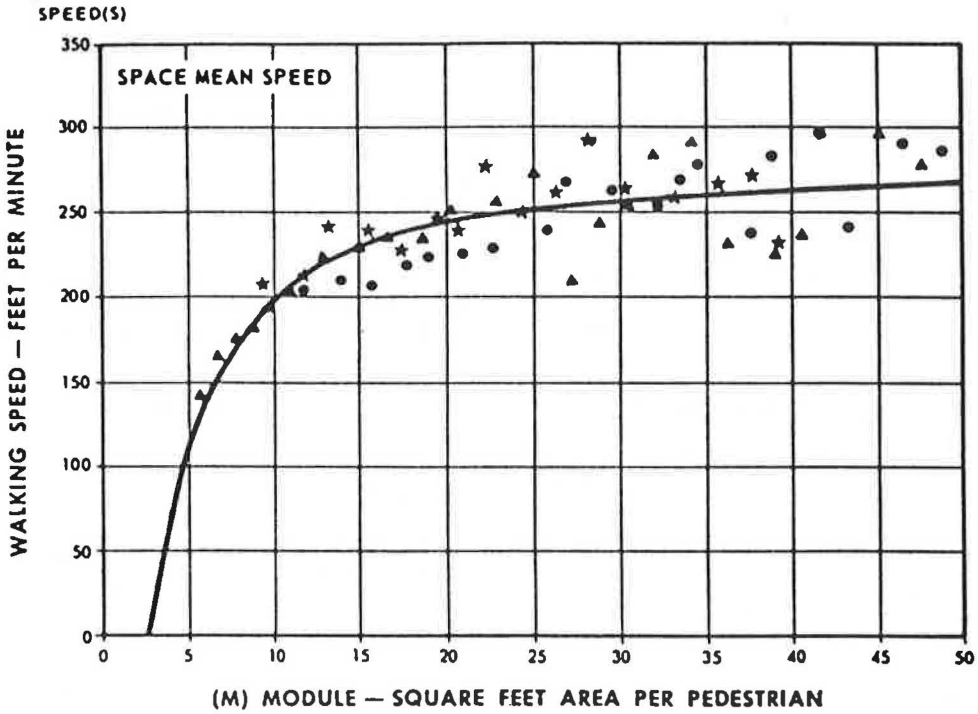

FIGURE 1 Relationship between pedestrian speed and space.

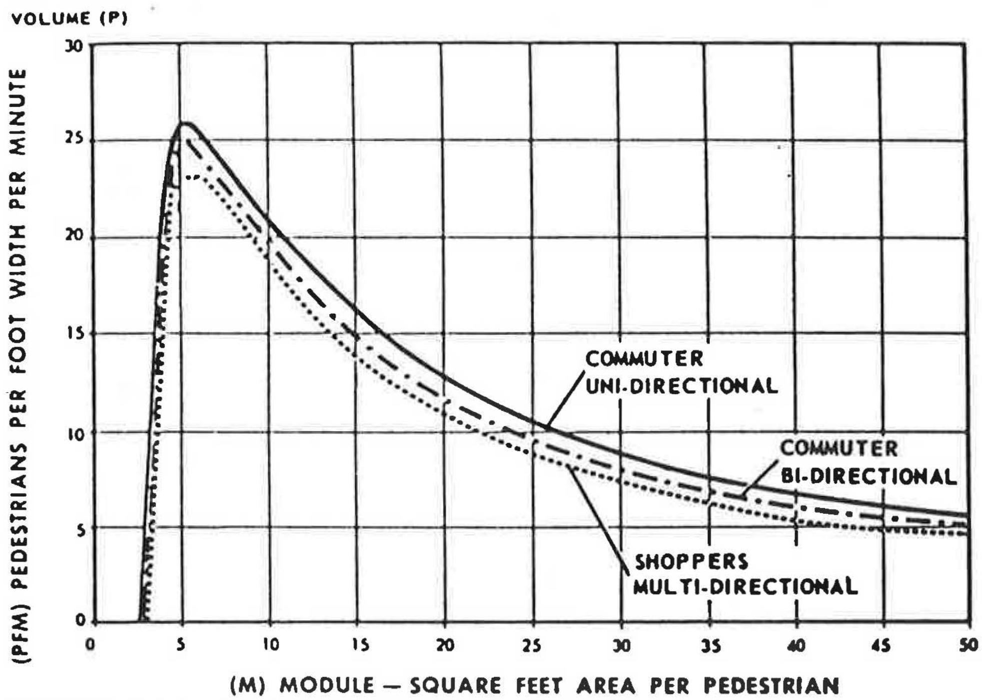

FIGURE 2 Relationship between pedestrian flow and space.

TABLE 1 Pedestrian Level of Service on Walkways: Average Flow Conditions *(5)*

Level of Service	Space[a] (sq ft/pedestrian)	Average Unit Width Flow Rate[a,b] (pedestrian/min/ft)	Average Speed[c] (ft/min)	Volume/Capacity Ratio[d]
A	Over 40	Under 6	Over 250	Under 0.24
B	24-40	10-6	240-250	0.24-0.40
C	16-24	14-10	224-240	0.40-0.56
D	11-16	18-14	198-224	0.56-0.72
E	6-11	25-18	150-198	0.72-1.00
F	Under 6	0-25	0-150	Variable

[a]These space per person and flow rates from Transportation Research Circular 212 vary slightly from those originally presented by Fruin *(2)*. Fruin's standards were developed for commuter facilities, while those above were developed for sidewalks, corners and crosswalks; however, both are similar in concept.
[b]Flow rates are relative to effective walkway widths.
[c]Speeds are computed from equation: Speed = Flow x Space.
[d]Assumed Capacity = 24 pedestrian/min/ft.

from A (best) to F (worst), on the basis of these relationships and on the relative probability of conflicts among pedestrians, comfort levels, and the ability of a person to walk at a desired speed along his path of choice. Each level of service is defined as a range of space per person values and flow rates (pedestrians per minute per foot width, or PMF), as shown in Table 1.

Fruin developed similar level-of-service standards for stairways and for queuing (waiting) areas (3). The queuing standards (Table 2) provide a range of areas per person and average interpersonal spacing (distance between people). The space that people require depends somewhat on the type of queue--ordered or linear and random or batch type--and the duration of time the person is in the queue. For instance, people crowding onto an elevator will tolerate close contact with strangers and accept 2 to 3 ft^2 of space per person (which is level of service E) because the expected duration of the condition is relatively short. However, on train platforms and similar waiting areas where passengers wait for a relatively long time, as much as 10 to 15 min, people will require 10 to 13 ft^2 of space per person.

These level-of-service standards, primarily based on the space needs of people involved in various activities, are widely used today for planning and design of facilities for pedestrians. Most often, however, these norms are applied to either average or peak volumes of people who will use the space over a given time period. The duration of the peak load condition or the amount of time that people will require the space is usually not considered. This disregard of the duration factor can lead to overdesign of the facility which, in the case of underground or elevated facilities, can waste capital funds.

In addition, the walking standards are generally valid only for linear flow, such as along a corridor. In areas with multidirectional flow or those with other activities occurring at the same time, such as a waiting area or the intersection of several corridors, the flow rate method of analysis is not valid.

TIME-SPACE CONCEPT

Conceptually, the time-space method considers pedestrian facilities as time-space zones with moving and standing pedestrians requiring different amounts of space and occupying the zones for different periods of time. Time-space is the product of an area (or space) and a time period (1). For instance, a pedestrian walking through a waiting room may require up to 24 ft^2 for movement, but will occupy that space for only a relatively short period of time, such as 10 sec. This would be 240 ft^2-sec or 4 ft^2-min. A pedestrian who is waiting on a platform requires 5 to 10 ft^2 for a longer period of time, such as up to 5 min. This would be equivalent to 25 to 50 ft^2-min. The time-space concept considers the type of activities occurring in a space within a given time period and the number of people who are involved in each. The amounts of time-space required for each activity are summed and compared to the time-space available or proposed within the facility.

TABLE 2 Pedestrian Level of Service on Stairways *(3)*

Level of Service	Space (sq ft/pedestrian)	Average Unit Width Flow Rate[a] (pedestrian/min/ft)	Description
A	20 or more	5 or less	Sufficient area is provided to freely select stair locomotion speed, to bypass slow pedestrians, and to easily permit reverse flows.
B	15-20	5-7	Virtually all persons may freely select stair locomotion speeds, but some difficulties would be experienced passing slower pedestrians; reverse flows present no serious conflict.
C	10-15	7-10	Stair locomotion speed would be restricted slightly due to inability to pass slower pedestrians; no serious conflicts with reverse flows.
D	7-10	10-13	Stair locomotion speeds would be restricted for the majority of persons due to the inability to pass slower pedestrians; reverse flows would encounter some conflicts.
E	4-7	13-17	Normal stair locomotion speeds reduced because of minimum tread length space and inability to bypass others; intermittent stoppages may occur; reverse flows experience serious conflicts.
F	4 or less	Variable to 17	Representative of complete breakdown in traffic flow with many stoppages.

[a]Flow rates are relative to effective walkway width.

Mathematically, the time-space concept can be described as

$$T\text{-}S_{req} = \sum P_i M_i T_i$$

where

$T\text{-}S_{req}$ = time-space required,
P_i = number of people involved in activity i,
M_i = space (area) module required per person for activity i, and
T_i = time required for activity i.

$T\text{-}S_{req}$ is compared to the time-space available ($T\text{-}S_{avail}$) to compare the adequacy of the space for the expected activities. $T\text{-}S_{avail}$ is the product of the area available (A_{avail}) and the time it is available (T_{avail}), or

$$T\text{-}S_{avail} = A_{avail} \times T_{avail}$$

Application of the Time-Space Concept

When the time-space concept is applied to solving a problem, any of the factors or elements defining the activities or spaces involved can be considered the unknown variable that is to be determined from the other known variables. For example, the time-space approach can first determine the amount of time-space required by waiting or queuing pedestrians. When this time-space for queuing activities is subtracted from the total time-space available, the remaining time-space available can be used for circulation (walking). The total time required by the walking pedestrian can be determined by estimating the average walk time per person through the space (which is a function of walk speed and distance) and multiplying it by the number of people walking through the space. Dividing the total time-space available for circulation by the total required walk time produces an area (square feet) per person that can then be compared to the pedestrian level of service criteria. This procedure, used in the study that follows, can be expressed as follows:

$$\text{Total } T\text{-}S_{avail} - \text{Queue } T\text{-}S_{req} = \text{Circ } T\text{-}S_{avail}$$

where

$T\text{-}S_{avail}$ = time space available,
Queue $T\text{-}S_{req}$ = queuing time-space required, and
Circ $T\text{-}S_{avail}$ = circulation time-space available.

and

$$\text{Circ } T\text{-}S_{avail} = \text{Circ S Per Person}_{avail} / \text{Circ } T_{req}$$

where

Circ $T\text{-}S_{avail}$ = circulation time-space available,
Circ T_{req} = circulation time required, and
Circ S Per Person_{avail} = circulation space per person available.

The case study that follows serves as an illustration of an application of the time-space concept to the analysis of spaces that handle high levels of pedestrian flow and a large number of waiting pedestrians. The case study is a rather simple application of time-space, but a variation is introduced later to demonstrate some of the other analytical capabilities of the time-space concept.

CASE STUDY DESCRIPTION

The case study involves a new passenger facility, referred to as a cross passageway, that will provide access to and from the ends of platforms of a busy commuter rail terminal that currently has access at one end only. The cross passageway is essentially a wide corridor that will run perpendicular to and above the platforms, with stairs connecting the cross passageway to each platform. The cross passageway is connected to the surface at several points. (See Figure 3.)

The cross passageway is to serve as a corridor for circulating passengers as well as a queuing area for passengers waiting for the opening of gates that provide access to the platforms from which their trains will depart. Passengers will assemble in the portions of the passageway adjacent to the gates. Surveys showed that passengers departing on trains typically start to gather in front of a gate about 23 min before the train's scheduled departure time and assemble at the following rates:

Time Before Departure (Minutes)	20	15	10	5	1
Departing Passengers (Percent Gathered)	9	26	53	86	100 (gates closed)

The maximum accumulation of passengers outside the gate to the train platform occurs just before the opening of the gate--typically 10 min before train departure when 53 percent of the passengers leaving on the train are present. The accumulation of waiting passengers, if large enough, can easily affect the cross passageway width available to handle longitudinal flow. The problem here is to examine whether the corridor can meet the space requirements of both queuing passengers and circulating passengers, at the design standard level of service, within a portion of the cross passageway adjacent to a departure gate. The analysis period is the 1 min before the opening of the gate when the maximum accumulation of waiting passengers will occur.

In this case study the 140-ft long portion of the cross passageway to be examined has an effective width of 25 ft (i.e., the width actually available for passenger activities: the wall-to-wall dimension minus the width occupied by obstructions and columns and the boundary or "cushion" maintained by pedestrians along walls). During the 1 min before the opening of the departure gate, 194 people will be waiting in the cross passageway. The flow rate of people walking along the corridor during this time will be 167 people per min.

With a design criterion of level of service C, the space per waiting person is 10 ft^2. This classification reflects the unordered (random) nature of the queue in this space, the need for some circulation and movement within the queue, and the comfort level expected by commuter rail passengers.

FLOW-RATE ANALYSIS APPROACH

This problem can be analyzed using the traditional flow-rate analysis method. This approach estimates the maximum number of people in the queue and the total amount of space they require. The 194 people waiting require 1,940 ft^2 (at 10 ft^2 per person). The shape of the queue has to be estimated in order to determine the portion of the 25-ft wide cross passageway the queue will occupy. In this case study, the waiting passengers, occupying 1,940 ft^2 and assumed to be evenly distributed along the 140-ft linear dimension of the space, are expected to require 14 ft at the widest point of the queue. This

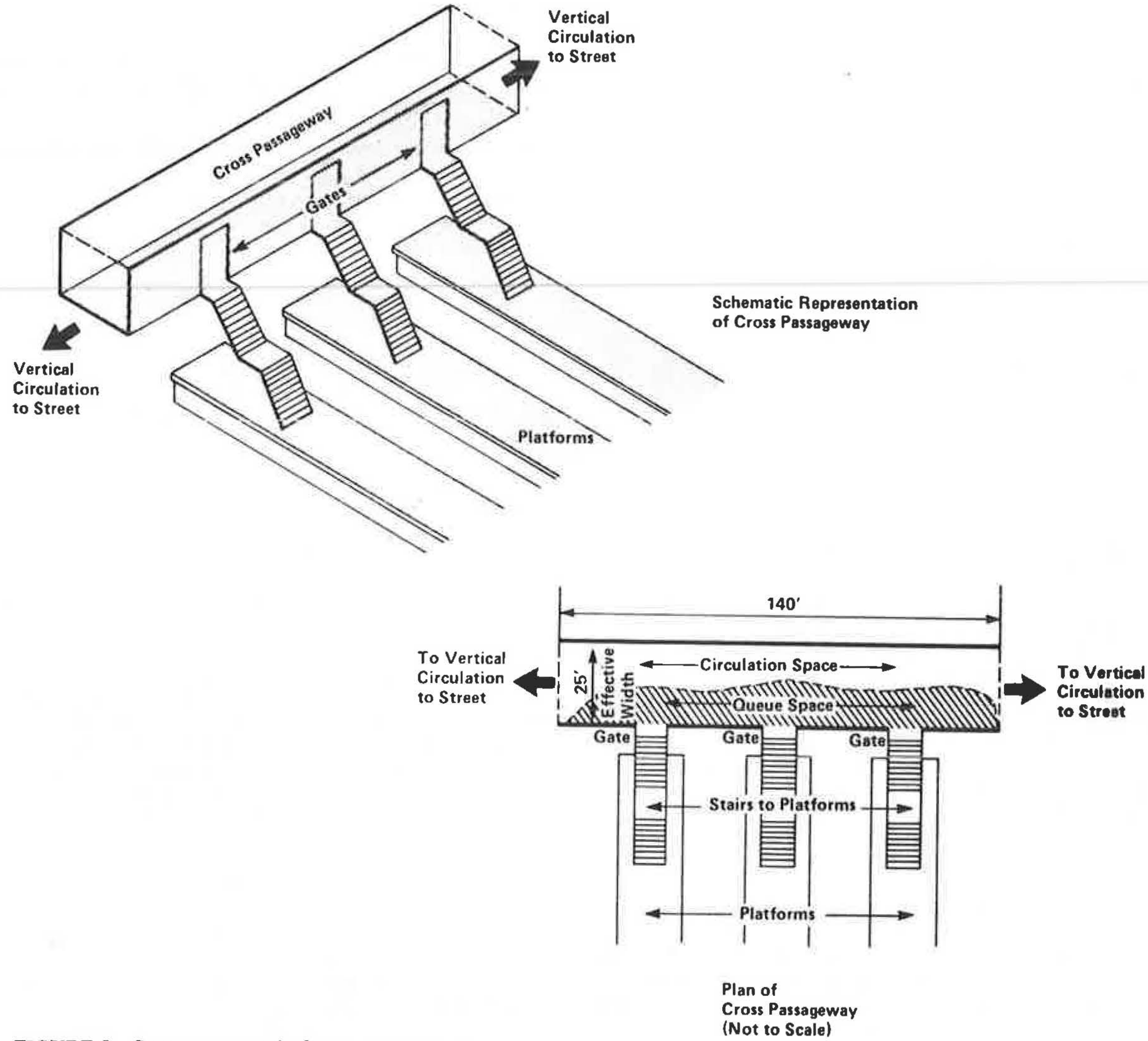

FIGURE 3 Commuter terminal cross passageway.

leaves 11 ft available for the flow of the 167 circulating passengers who would walk through the cross passageway during the 1 min peak queue period. The flow rate per minute per foot width of corridor available is 15.2. This rate equates to level of service C/D, using the flow-rate level-of-service standards, which means that the condition is at the 15 pedestrians per min per ft width (PMF) boundary between levels of service C and D.

TIME-SPACE APPROACH TO PROBLEM

The time-space approach to this problem is first to determine the amount of time-space available in this portion of the cross passageway. The time-space required by the waiting passengers is then deducted from the total time-space available. The remaining time-space is available for the circulating (walking) passengers. The total walk time spent in the area by the circulating passengers is determined, which, when divided into the time-space available for circulating passengers, gives the area per person for circulating passengers. This figure can then be equated to pedestrian level-of-service standards.

The cross passageway (140 ft long and 25 ft wide) has an area of 3,500 ft^2. Within the 1-min analysis period, the time-space available for all pedestrian activities in the cross passageway is 3,500 ft^2-min (3,500 ft^2 x 1 min), that is, 3,500 ft^2 are available for pedestrian activities for 1 min.

The 194 people waiting during the maximum 1-min peak period before the opening of the gate will require 10 ft^2 per person (which is equivalent to level of service C). This equals 1,940 ft^2-min required by the waiting passengers (194 people x 10 ft^2/person x 1 min). Subtracting this from the total time-space available in this cross passageway segment, leaves 1,560 ft^2-min available for circulating passengers (3,500 ft^2-min - 1,940 ft^2-min).

The 167 persons who will walk through the cross passageway during the 1-min period will require 0.62 min to traverse the space at a walk speed of 225 ft/min. Flow-rate analysis showed the flow rate in the corridor to be 15 pedestrians per min per ft width. Referring to Figures 1 and 2, this equates to a walk speed of 225 ft^2/min. The total walk time required by the 167 pedestrians is 104 person-minutes (167 people x 0.62 min).

The time-space available for these circulating pedestrians is 1,560 ft^2-min. The area per pedestrian is found by dividing the time-space available for circulation (1,560 ft^2-min) by the total time required by the circulating passengers (104 person-minutes). The result is 15.0 ft^2 per person. This area per person is then compared to the pedestrian level of service standards, which, for this example, is the border of level of service C and D. This is

considered an acceptable level of service for the maximum peak condition.

The calculation steps are summarized as follows:

1. Total space available: Length x Width = 140 ft x 25 ft x 3,500 ft^2.

2. Total time-space available: Space available x Time period = 3,500 ft^2 x 1 min = 3,500 ft^2-min.

3. Total queuing time-space: Number of people in queue x Time in queue x Queue area per person = 194 people x 1 min x 10 ft^2/person = 1,940 ft^2-min.

4. Time-space available for circulation: Total time-space available - Total queue time-space = 3,500 ft^2-min - 1,940 ft^2-min = 1,560 ft^2-min.

5. Walk time per person: Walk distance ÷ Walk speed = 140 ft ÷ 225 ft/min = 0.62 min/person.

6. Total walk time: Number of people x Walk time per person = 167 people x 0.62 min/person = 104 min.

7. Area per person for walking: Total time-space available for circulation ÷ Total walk time = 1,560 ft^2-min ÷ 104 min = 15.0 ft^2/person, 150 ft^2/person → Level of Service C/D.

Refinement Step

An important feature of the time-space method is that it can be used to evaluate the impact of activities that cannot be quantified by other methods, as illustrated in the following example.

A significant number of passengers will need to stop momentarily or slow down to read the information screen to determine the platforms from which their trains will depart. This activity will consume a certain amount of time-space and the impact of this pausing on the cross passageway can be analyzed within the context of the initial case study.

Of the 167 persons who will walk through the cross passageway, an estimated 60 percent will stop or slow down to read the information screen. Each person will take an average of 3 sec to read the screen and will occupy about 5 ft^2 during that activity. Therefore, the time-space required for this activity is 25 ft^2-min (167 persons x 60 percent x 3 sec/person x 5 ft^2/person - 60 sec/min). This amount can be added to the time-space required by the pedestrians in the passageway segment. Of the 3,500 ft^2-min available in the cross passageway, the waiting pedestrians will require 1,940 ft^2-min while the time-space requirement of those stopping or slowing to read the information screens is 25 ft^2-min. The remaining time-space available for the circulating passengers is 1,535 ft^2-min. The total walk time is 104 person-minutes. Dividing this remaining time-space available by the walk time required results in an area per person of 14.8 ft^2 for walking that equates to a level of service C/D.

The refinement described earlier had only a marginal effect on the results. It demonstrates, however, the capability of the time-space concept to examine problems at different levels of detail and treat each of the activities in the space discretely. Different groups of people within the total population of users can be treated separately. For instance, the walk time-space requirements for people encumbered with luggage, or small children, or characteristics of the user population can be included in the time-space analysis.

COMPARISON OF ANALYTICAL TECHNIQUES

When the cross passageway segment was analyzed using both the time-space technique and the more conventional flow-rate method, the different approaches produced similar results. The time-space technique result was 15 ft^2 per person, which is on the boundary between levels of service C and D. The flow-rate method result was 15.2 PMF which, in a strict sense, is level of service D. Because the boundary between levels of service C and D is 15 PMF, this level of service is very close to level of service C.

Although both methods produce similar results, the advantage of the time-space technique is that it analyzes the entire space, not just the narrowest point of one dimension of the space. Furthermore, as observed here and as will be observed in the subsequent application studies, the time-space technique can account for pedestrian activities and behavior such as stopping to read the information screen, which is not readily addressed by available methods.

Although the flow-rate technique, as applied here, has the advantage of considering the amount of cross passageway width consumed by the waiting passengers and the amount of width available for circulation, the time-space technique can be applied in such a way as to take this factor into account. (In this example, the constricted corridor width affected the longitudinal walk speed, which was reflected in the walk time-space requirement.) Where such issues are of major concern, both techniques should be applied.

In a recently completed master thesis study at Carleton University, Grigoriadou (6) applied the time-space concept to a train platform and found that this concept can replicate observed and measured pedestrian level-of-service conditions. In addition, ongoing research by the author reveals that the time-space concept can model spaces (station mezzanines) in which a variety of activities take place, including multidirectional passenger flow. The time-space requirement for each walking, queuing, and processing activity is calculated separately, summed, and compared to the time-space available. Another study involved dividing a platform into several time-space zones, calculating the walking and waiting time-space requirement for each zone, and comparing the result to the time-space available in that zone. In this way, conditions in a specific part of the platform can be analyzed, instead of being treated in the aggregate, as traditionally done.

CONCLUSION

The time-space concept offers a means of analyzing pedestrian activity spaces that could not be adequately analyzed using other methods. Time-space, a new way of thinking about these facilities and how they are used, introduces the time dimension into the analysis by including the amount of time a space is required. The time-space approach is a new tool for planners and designers who must size and evaluate these spaces. Not necessarily a replacement for the existing techniques in all situations, the time-space approach is a superior method for many types of spaces that could not be analyzed before.

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BART Patron Egress/Ingress Study: Use of Stairs and Escalators Between Platform and Concourse Levels

MATT du PLESSIS

ABSTRACT

The shorter headways planned for 1989-1990 and the increased patronage projected over the next 5 years caused concern about the capacities of the Bay Area Rapid Transit (BART) stations to handle exiting patron loads. A basic objective at BART has been that patrons from one train should be off the platform before the next train coming from the same direction arrives; that is, within the existing headway. To analyze the patron egress/ingress capacities of BART's stations, five parameters were considered: (a) the planned headways between trains, (b) the projected patronage at each station, (c) the availability of escalators, (d) the processing rates for the stairs and escalators, and (e) the number of patrons that can be expected to use the stairs. On the basis of these five parameters, a basic criterion was developed: The projected 95th percentile of peak patron loads during the exit rush 2 hours should be able to use the stairs and escalators to exit the platform within 2.25 min, even if one escalator is unavailable. Each station was analyzed under four conditions. The analysis revealed that nine stations would have problems in the 2.25-min time frame when one escalator is unavailable. Each of the nine stations was evaluated in detail, and preliminary recommendations were made for the number of escalators or stairs to add to the stations. To facilitate a decision on constructing an escalator or stairwell at each station, cost estimates should be obtained and considered in light of the indicated severity of potential egress/ingress problems.

The Bay Area Rapid Transit District (BART) will be experiencing significant changes by 1990. The new C-cars will be added to the fleet of revenue vehicles, and the Daly City extension track will have been constructed. At the same time, BART staff are planning to reduce headways between trains to 2.25 min in 1989, and patronage is projected to increase by 40 to 45 percent in the next 5 years. A critical issue for BART is the egress/ingress capacity of the stations under these conditions. Is there enough escalator and stairway capacity to handle projected volumes of patrons?

The manager of station operations asked management services to conduct an analysis of the egress/ingress capacity of the stations to determine (a) which stations, if any, would not be able to handle the projected patronage increases within the shorter headways; and (b) the estimated number of escalators or stairways needed to handle the increased load.

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The issue of additional faregates and other automatic fare collection (AFC) equipment was not considered a part of this study, but will be addressed by the AFC Study Committee.

Described in this paper is the analysis of the station egress/ingress capacities between the platform and concourse level only. The concourse-to-street-level capacities are not expected to be as critical as the platform-to-concourse capacities and were analyzed in a separate study.

The analysis described in this paper will demonstrate the method used to evaluate station egress/ingress capacities. The analysis was based on current patronage projections for 1989-1990. Based on this analysis, those stations that may have egress/ingress problems will be identified, and the number of escalators or stairwells recommended for adequate capacities under adverse conditions will be presented. The actual locations and cost estimates for installing escalators and stairs will be determined separately by design engineering staff.

To evaluate whether the escalator and stairway