Evaluation of Pedestrian Walking Speeds in Airport Terminals

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Despite the fact that significant investment has been made to install automated pedestrian movement systems within airport terminals, little is known about their effects on airport pedestrian flows. Specifically, while walking speeds of pedestrians have been studied in general, such analysis specific to airport passengers has been lacking. New insight into the walking speeds of airport pedestrians is provided. Corridors with and without moving walkways, the most common of airport automated pedestrian movement systems, are considered. Pedestrian movements in various airport terminal corridors are empirically observed, and observed walking speeds are compared with those of research performed in other transportation terminals. Furthermore, the effects on walking speeds of observable characteristics of pedestrians and the surrounding environment are investigated. The effect of moving walkways on pedestrian walking speeds is examined. A methodology for estimating the travel time of pedestrians on moving walkways under various traffic-flow conditions is derived. Application of the methodology using empirically collected data reveals interesting results about the movement of pedestrians through corridors with moving walkways. The analysis presented may be used to estimate expected travel times in airport corridors, and to examine the effects of potential infrastructure investments on such times. The goal of such an analysis is to improve the quality of service at the airport terminal, particularly for the pedestrians who traverse its corridors.

On February 17, 1998, the *Detroit Free Press* (*1*) published a front-page article describing the dissatisfaction of passengers with the city's major airport, Detroit Metropolitan International (DTW). The article began with a quote from a frequent DTW traveler who stated, "It's just too far to walk between flights. At 5 o'clock, this place is a mob scene. . . ." For the majority of passengers traveling through DTW, distances to travel between facilities within the terminal may be considered excessive. Often, such distances must be covered under time pressures, especially for passengers making connections between flights. Travel within the terminal often is made via circuitous routes through narrow corridors. Despite the presence of moving walkways in several corridors, complaints of long travel distances prevail.

The opinions of these passengers were supported by the results of a nationwide survey of airport quality, which accompanied the article. The survey of 90,000 air passengers rated the quality of the nation's 36 most heavily traveled airports. Airports were rated under eight categories, including walking distances between terminal facilities and accessibility to ground transportation and parking. Ranked last in the survey was DTW.

The problems associated with intraterminal travel at DTW are a result of the airport's history of incremental expansion to accommodate increased passenger enplanements and aircraft operations. In addition, use of DTW as a hubbing facility by Northwest Airlines has forced passengers traveling between gates to move through a terminal never intended to handle large amounts of connecting traffic.

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In an effort to improve conditions at DTW, the airport authority has proposed to construct an entirely new terminal and decommission the present facility. Interestingly, the proposed terminal does little to reduce the walking distances that presently frustrate so many DTW passengers. The new $786 million terminal will incorporate automated pedestrian movement systems to aid passengers traveling within the facility. It is interesting to wonder why the designers of the new terminal believe that such systems will be highly valued by passengers, especially when little value seems to be placed on such systems in the current facility. In reality, little is known about how, when, and why passengers value such systems in airport terminals. The research presented contributes to gaining a better understanding of how pedestrians behave within terminal corridors, with specific regard to walking speeds in various environments, so that more knowledgeable decisions may be made when designing terminal facilities.

BACKGROUND

While little is known about the walking speeds of pedestrians specifically within airport terminals, a good amount of research has been published on the behavior of pedestrians in a variety of related environments. Fruin (*2*) conducted a series of studies on the behavior of pedestrians within transportation terminals. Two studies in particular—conducted at the Port Authority Bus Terminal, and at the Pennsylvania Train Station, both located in New York City—observed pedestrian walking speeds under free-flow conditions along with various observable pedestrian characteristics. Among the included characteristics were approximate age, gender, trip purpose, number of bags carried, direction of travel, size of the pedestrian's party, and final destination within the terminal or vicinity. Fruin's research yielded a distribution of free-flow walking speeds for the environments of study. As shown in Figure 1, Fruin found that the mean walking speed was approximately 80.8 m (265 ft) per minute, with a standard deviation of 15.3 m (50 ft) per minute. Within these studies, he found no significant variation in a pedestrian's free-flow walking speed with respect to any directly observable pedestrian characteristics. He did, however, find that certain characteristics, such as the density within a corridor, affected the ability of pedestrians to achieve free-flow walking speeds.

Free-flow walking speed is achieved in situations in which pedestrians walk in a direct, unimpeded fashion. Such speeds are attained in areas where the density of traffic is sufficiently light. Fruin states that in terminal areas without cross-directional flow, free-flow speeds generally are achieved when the modulus, or inverse density, of traffic is less than or equal to 2.3 m^2 (25 ft^2) per pedestrian. At higher densities, walking speeds decline rapidly as the available clear area for locomotion decreases. The one exception to this rule is when

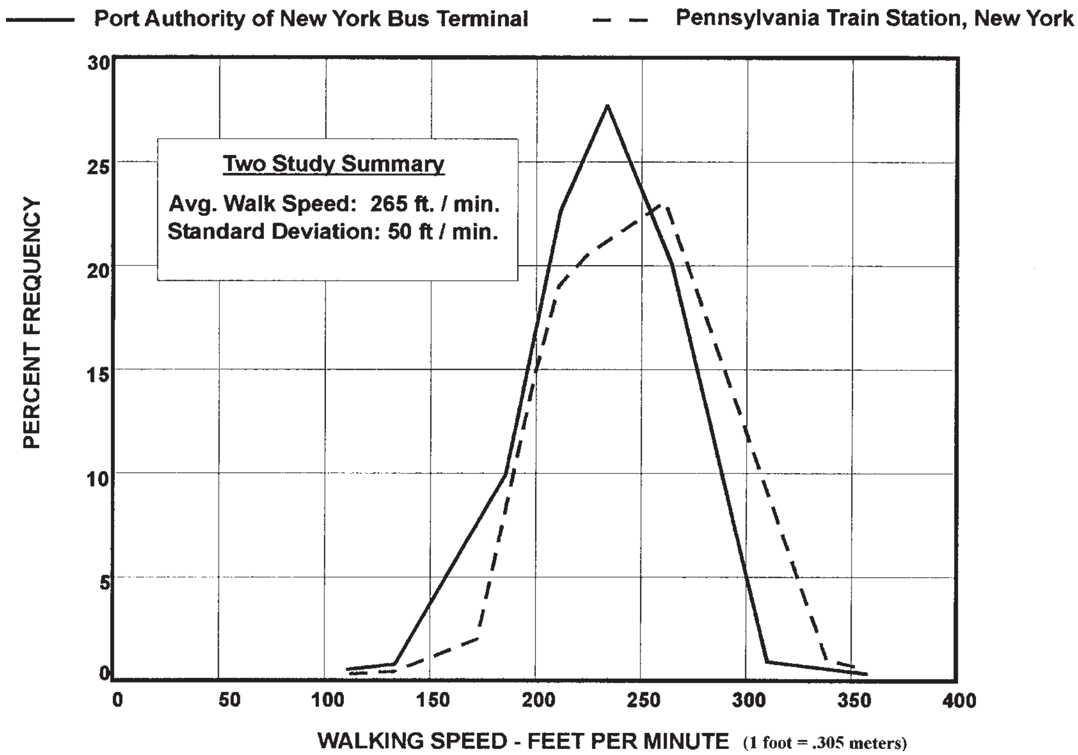

FIGURE 1 Distribution of unimpeded free-flow pedestrian walking speeds. Source: Fruin, *Pedestrian Planning and Design,* 1971.

pedestrians walk in a synchronous manner, in which case they can maintain free-flow walking speeds even when in close proximity to one another. When cross-directional flow or standing pedestrians exist, the impedance to free-flow walking increases. This is due to the increased probability of conflicts between through and cross-traffic. In areas of cross-flow and standing pedestrians, Fruin reveals that impedance due to flow conflicts becomes negligible at moduli no less than 3.3 m^2 (35 ft^2) per pedestrian.

While Fruin's findings have been accepted for pedestrians in general, little is known about the applicability of these findings to airport pedestrians in particular. Furthermore, the walking-speed behavior of airport pedestrians on moving walkways has yet to be fully understood. To fill this research need, similar observations were performed, with the primary focus on airport pedestrians, both on and off moving walkways in terminal corridors.

ANALYSIS METHODOLOGY

Empirical observations, similar to that of Fruin, were taken of pedestrian movements within airport terminal corridors. Observations were made in various corridors at San Francisco International Airport and Cleveland Hopkins International Airport. At San Francisco International Airport, data were collected by following randomly selected parties of passengers through a corridor. For each observation, the approximate age (to the nearest decade), gender, and travel type (business or leisure) for each pedestrian in the party were recorded. The party size, number of bags carried, and direction of travel were recorded as well. The personal characteristics were recorded using the best judgment of the observation team. For instance, characteristics of a pedestrian's attire and baggage were the primary basis for judging the purpose of the trip. Another characteristic requiring judgment to assess was the amount of baggage being carried. In general, any item larger than a purse was considered to be a baggage item. No discrimination as to the apparent weight of an item or how the item was carried (e.g., over the shoulder, toted along wheels, or lifted) was made. Observations of pedestrian movements also were made by videotaping pedestrians entering and exiting the corridors of study. All personal characteristics of pedestrians were recorded, along with pedestrian mode choices. Through video recording, all observable pedestrian characteristics and pedestrian travel times through the corridor were captured. In addition, the videotape data allowed for a comprehensive, dynamic analysis of pedestrian flows through the corridor. In total, approximately 1,000 observations were recorded at the two airports of study.

Analysis of these observations revealed that, under free-flow conditions, airport pedestrians behave in a manner similar to those in Fruin's study of other transportation terminals, with an average free-flow walking speed of 80.5 m (264 ft) per minute, approximately normally distributed with a standard deviation of 15.9 m (52 ft) per minute. Table 1 summarizes this finding.

Similar to Fruin's study, there was no significant variation found in the free-flow walking speed with any observed pedestrian

TABLE 1 Observed Free-Flow Walking Speeds, ft/min (m/min)

Study	Mean walking speed	Standard Deviation
Fruin (1971)	265 (80.8.)	50 (15.3)
SFO / CLE	263.26 (80.5)	52.49 (15.9)

SFO = San Francisco International Airport; CLE = Cleveland Hopkins International Airport.

TABLE 2 Observed Free-Flow Walking Speeds by Pedestrian Characteristics, ft/min (m/min)

Gender	Male	Female
Sample average	277 (84.4)	253 (77.0)
Sample standard deviation	57 (17.4)	
t-statistic = 1.9		
Bags	**No**	**Yes**
Sample average	258 (78.7)	270 (82.4)
Sample standard deviation	48 (14.6)	44 (13.4)
t-statistic = -0.9		
Direction of travel	**Departure**	**Arrival**
Sample average	260 (79.1)	269 (82.2)
Sample standard deviation	53 (16.3)	34 (10.4)
t-statistic = -0.8		
Travel type	**Business**	**Leisure**
Sample average	272 (83.1)	261 (19.6)
Sample standard deviation	43 (13.0)	47 (14.5)
t-statistic = 0.7		

characteristics. These include the pedestrian's apparent age, the presence of baggage, the direction of travel, and the pedestrian's party size. The findings are summarized in Table 2. (The two-sample difference of means test using 95 percent confidence levels was used to test for statistical significance.)

There were occasions when free-flow speed was possible but pedestrians walked more slowly or even stopped intermittently. There were two primary situations in which this behavior tended to occur. Pedestrians had a tendency to reduce their walking speeds when a travel-path decision was approaching. One such situation was found at points of juncture, such as entrances to other corridors, to concession areas, and to airport destinations such as gate boarding areas, baggage claim, and ground-transportation areas. In addition, the presence of information systems, such as directional signs and aircraft arrival-and-departure boards, was found to cause pedestrians to alter their speed.

Initial results based on the data collected at San Francisco International Airport revealed that the travel time of pedestrians traversing airport corridors varied significantly with the mode with which they chose to move. These results motivated an analysis of free-flow walking speeds for those pedestrians who chose to bypass any present moving walkways as well as for those who chose to use moving walkways in some manner.

Upon further analysis of those pedestrians who chose to bypass, it was revealed that the free-flow walking speeds of these pedestrians again did not differ significantly from Fruin's results. Figure 2 illustrates the distribution of pedestrian walking speeds for those who bypassed moving walkways, as compared to Fruin's observations. These results were somewhat surprising. In particular, it was expected that bypassers would have a slightly higher mean walking speed as a result of self-selection, that is, those pedestrians with lower natural walk speeds would choose to use the moving walkway. From the data, however, it was found that pedestrian walking speeds upstream of a corridor had no significant correlation to mode choice or moving-walkway walking speed. Furthermore, in nearly every observation, the walking speed of a pedestrian bypassing the moving walkway was observed not to change on entering the corridor from upstream. It is hypothesized that those pedestrians who have extremely low walking speeds tend to use special transit services found at most airports. Such services, including wheelchairs and courtesy carts, effectively remove such pedestrians from the observed population.

The free-flow walking speeds of pedestrians who chose to use moving walkways and walk more than a trivial distance [defined by achieving a minimal average walking speed of 9.2 m (30 ft) per minute] varied significantly from those who chose to bypass. (Whether a pedestrian was traveling at a free-flow walking speed was evaluated using the best judgment of the observation team. Judgment was based primarily on an observed absence of downstream obstructions on the moving walkway that would alter the pedestrian's speed.) These pedestrians tended to travel with lower walking speeds, averaging 62.2 m (204 ft) per minute with a standard distribution of 28.1 m (92 ft) per minute. Figure 3 illustrates that the distribution of walking speeds is somewhat bimodal, with a portion of pedestrians traveling with walking speeds comparable to those bypassing the walkway and a portion of pedestrians traveling at much lower speeds, primarily within the range of 9 to 28 m (30 to 90 ft) per minute.

These behavioral differences result from the physical characteristics of the walkway itself. The relatively narrow width, rubber belt footing, and belt speed of a typical moving walkway are all possible reasons for lower walking speeds of walkway users. In addition, the fact that moving walkways provide forward propulsion via a moving belt gives incentive to pedestrians to reduce their walking speeds while

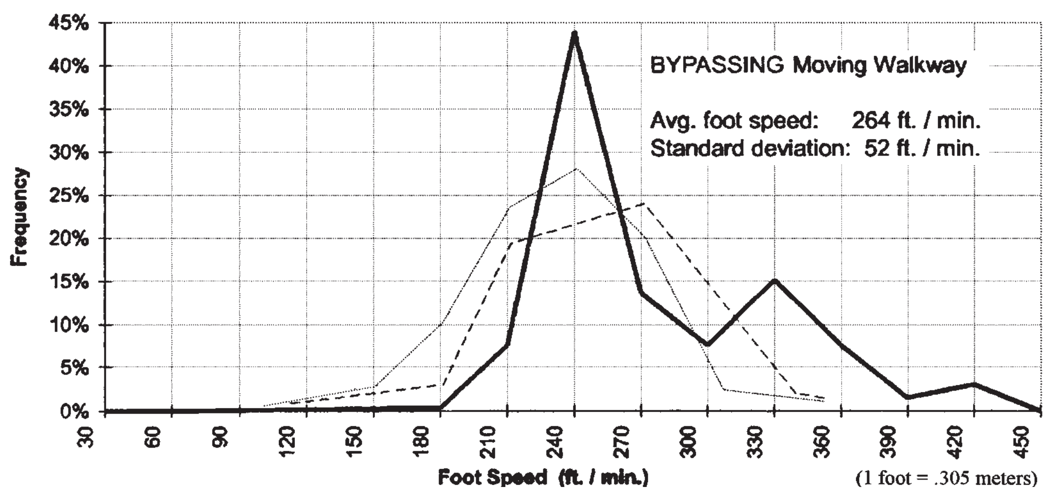

FIGURE 2 Distribution of pedestrian walking speeds: bypassing moving walkways.

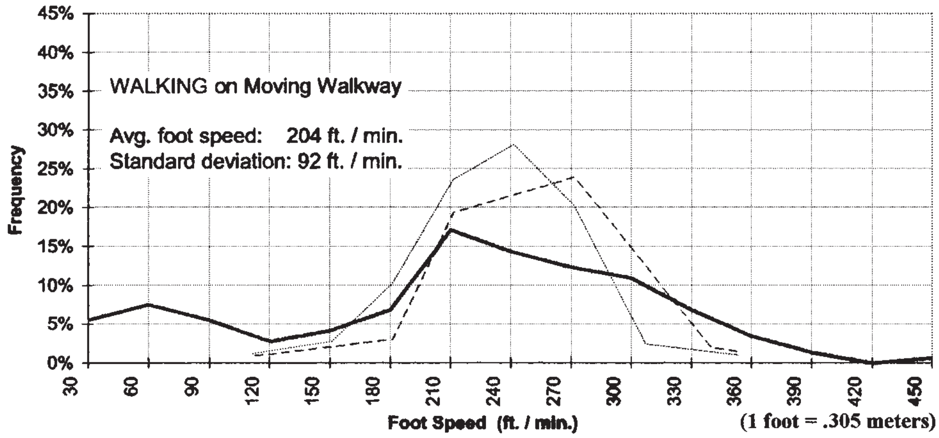

FIGURE 3 Distribution of pedestrian walking speeds: walking on moving walkways.

still completing their trip through the corridor in a timely manner. (The level of incentive to reduce walking speed also may be a function of individual pedestrian characteristics, such as baggage carried, party size, etc. Determining the factors that affect a pedestrian's *choice* to reduce walking speed is being addressed in ongoing research.)

A cumulative distribution of pedestrian walking speeds was derived, taking into consideration the distribution of walking speeds for both bypassing and walking pedestrians in corridors with moving walkways and the observed mode split of bypassing, walking, and standing passengers. Figure 4 illustrates this derived cumulative distribution for the observations made at San Francisco as compared to a similar distribution of pedestrian walking speeds in which moving walkways were absent. Figure 4 illustrates that moving walkways within airport corridors in fact reduced the overall walking speeds of pedestrians by allowing both standing and very low walking speeds. These options were chosen by approximately 20 percent of moving-walkway users.

While moving walkways have been observed to reduce congestion within airport corridors, they also potentially introduce congestion, which may affect the ability of pedestrians to travel at free-flow walking speeds. The Federal Aviation Administration (FAA) and the International Air Transport Association (IATA) have strongly recommended that airport terminal corridors have at least a total of 6 m (20 ft) of available width in which pedestrians can walk, not including any passenger movement systems such as moving walkways that may be present in the corridor. At these design widths, unidirectional flow densities are thought to rarely, if ever, become sufficiently great to induce congested conditions. In corridors of sufficient width, moving walkways may be installed. In the environments studied in this research, every corridor with a moving walkway conformed to FAA-IATA recommendations. Locations in the airport where moving walkways were not installed were narrow gate concourse corridors, rotundas, and areas of major congregation, such as ticketing and baggage claim areas. It is precisely these locations where high levels of cross-flow and density, entranceways to other corridors and ancillary facilities, and access to information systems either force or invite passengers to travel at less than free-flow speed. Reductions in passenger speed due to increased densities and cross-traffic may be estimated from results found in previous research. Navin and Wheeler (*3*) provide a currently accepted speed-density relationship for uniform pedestrian flow. Fruin contributes to this relationship by incorporating the probability of conflicts due to standing or cross-flow traffic.

Under certain conditions, moving walkways may affect the walking speeds of bypassers. The presence of moving walkways in a corridor reduces the effective width of the corridor. While the remaining width usually is sufficient to maintain unidirectional free-flow walking speeds, the effect of standing or slow-moving passengers becomes severe more rapidly. This situation is common in corridors not originally designed to accommodate moving walkways. Often, these moving walkways are placed in the center of gate concourse corridors. Such is the case at St. Louis's Lambert Field. During minutes prior to departure, passengers in aircraft boarding areas tend to "spill over" into through corridors. Prior to the installation of moving walkways, this spillover effect had relatively minor consequences. With the presence of moving walkways, however, passenger spillover effectively blocks the corridor between the moving walkway and the gate boarding areas.

While moving walkways may increase the effects of standing traffic in the corridor, their presence also reduces cross-flow traffic. A moving-walkway system effectively blocks direct access between cross-concourse locations. In addition, moving walkways act as a directional aide, resulting in less milling by pedestrians attempting to orient themselves. For the corridors studied in this research,

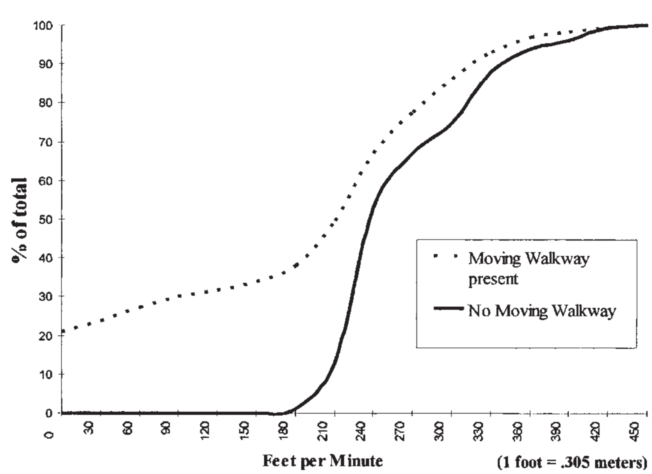

FIGURE 4 Cumulative distribution of pedestrian walking speeds.

congested flow conditions virtually were nonexistent. Only during very brief periods did the situations described above occur.

Pedestrians walking along a moving walkway often are obstructed by downstream pedestrians who are walking at a slower pace or standing. Such obstructions may affect average pedestrian walking speeds, which in turn affect travel times and walking distances. Consider the simple situation in which a walking passenger becomes obstructed by a downstream stander on a moving walkway. This situation may be illustrated graphically by means of a time-space diagram, represented in Figure 5. (Daganzo [*4*] provides a detailed discussion of time-space diagrams.) The figure illustrates the boarding of a walker onto a moving walkway of length L, t_1 time units after a person boarded the walkway and chose to stand for the length of the trip, traveling at a speed s, where s equals the belt speed of the walkway. For a short time, the walker travels at a total speed of $w + s$, where w equals the walking speed of the walker on the walkway. At some point along the walkway, the walker becomes obstructed by the downstream stander. From this point until the end of the moving walkway, the walker stays n time units behind the stander, where n equals the minimum egress headway between moving-walkway users.

From the information given in Figure 5, the average travel speed of the upstream walker may be calculated as

$$\bar{v} = \frac{L}{t_2 - t_1 + n} \tag{1}$$

where

t_1 = boarding headway between stander and walker,
t_2 = egress time of stander (L/s),and
n = minimum headway between passenger egress.

The total travel time of the walker on the moving walkway (including obstructed and unobstructed travel) is as follows:

$$TT = \frac{L}{s} - t_1 + n \tag{2}$$

Figure 6 represents a situation in which a sequence of walking passengers becomes obstructed by a single downstream stander. In this example, walkers board the walkway at equal intervals of time t_1 and travel at an unobstructed speed w.

The average travel speed of the kth walker in the series is

$$\bar{v}_k = \min\left\{\frac{L}{[L/s] - k[t_1 - n]}, w + s\right\} \tag{3}$$

and the total travel time of the walker on the moving walkway (including obstructed and unobstructed travel) is as follows:

$$TT_k = \max\left\{\left[\frac{L}{s} + kn - kt_1\right], \frac{L}{w+s}\right\} = \frac{L}{\bar{v}_k} \tag{4}$$

In many circumstances, moving-walkway users who encounter slower-moving downstream pedestrians may wish to pass, or overtake, one or more such obstructions. The benefits of such actions include the ability to continue walking at free-flow speed, more or less, resulting in a shorter travel time than if overtaking were not performed. Figure 7 illustrates the reduction in travel time as a result of a single walker overtaking a downstream stander. Note that TT_0, the travel time of a pedestrian given that the downstream obstruction was not passed, is indeed greater than TT_1, the travel time of the pedestrian on overtaking. The disadvantage to overtaking any number of downstream obstructions is the extra amount of pedestrian effort that may be required to perform such a maneuver.

From the data, observed travel times of all pedestrians traversing the corridor of study may be directly recorded. In addition, for those pedestrians observed to be using the moving walkways and walking, the number of downstream obstructions passed by each pedestrian is extracted from the data. From these observations, the unobserved travel times of choices available to but not actually made by pedestrians may be derived using the above methodology.

It is important to note that the methodology followed in this research assumes a constant velocity of pedestrians traveling on moving walkways, resulting in the trajectories illustrated in Figure 7. This assumed behavior has no effect on the total travel time of observation k or on any upstream observations that follow. What is affected, however, are the assumed locations of pedestrians along the moving walkway itself at any given point in time. Enriching

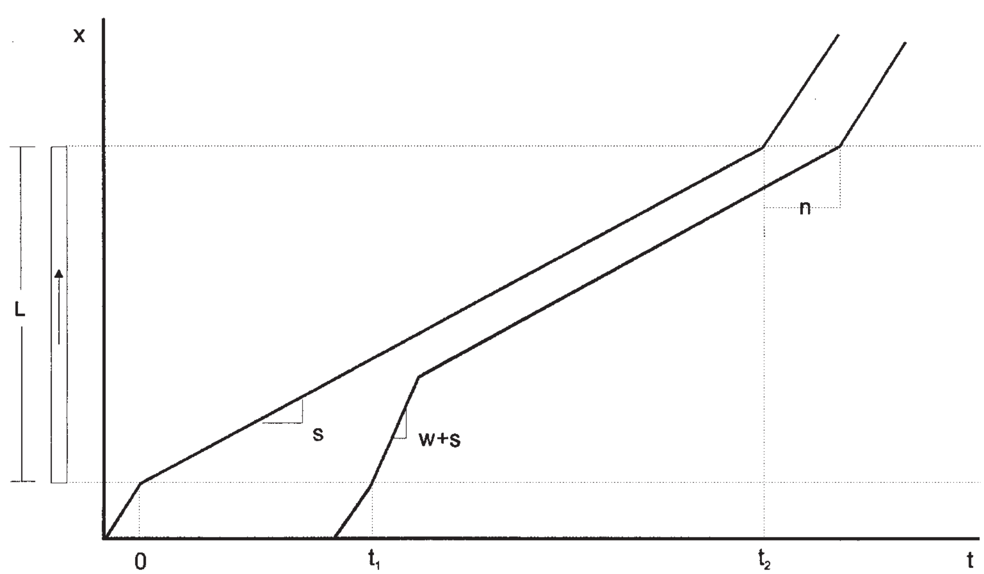

FIGURE 5 Time-space diagram representing a single downstream obstruction.

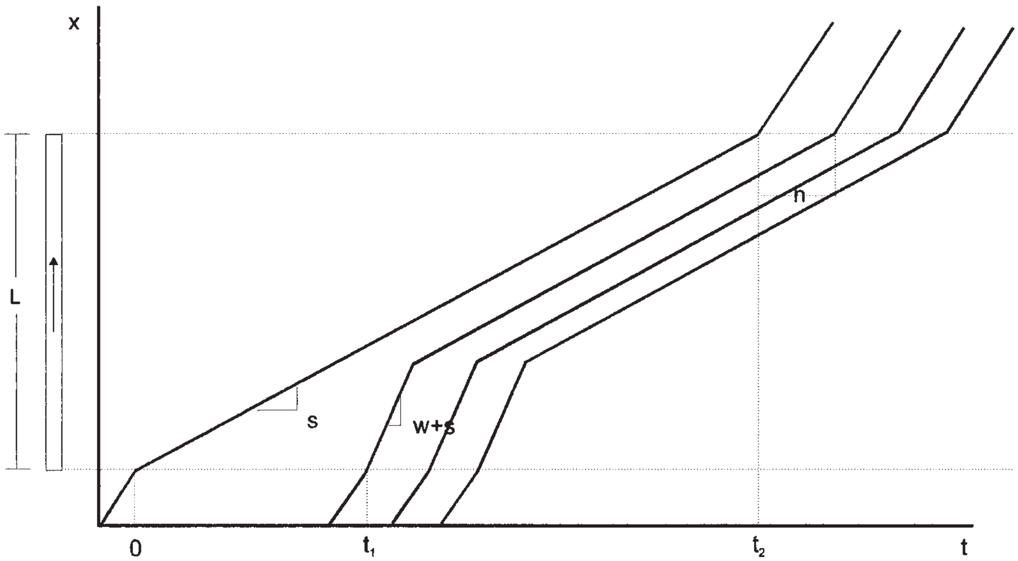

FIGURE 6 Time-space diagram representing a series of downstream obstructions.

the data by increasing the number of recording stations along the path of the moving walkway would provide further insight into this issue.

The reduction in pedestrian walking speeds on congested conveyors may be evaluated when applying the observed data to the above derivation. Observations of pedestrians walking on various congested moving walkways (defined as having downstream obstructions that, if not overtaken, would increase the travel time of an upstream walker) revealed that only approximately 20 percent of the walkers observed passed all existing obstructions. Thus, 80 percent of all walkers experienced increased travel times due to slower-moving downstream passengers. Table 3 summarizes the estimated reduction in average pedestrian walking speeds of these walkers. As the table confirms, those pedestrians who use moving walkways tend to do so with significantly reduced walking speeds, whether it is under free-flow or the above "congested-flow" conditions.

Of course, it is generally feasible for pedestrians to avoid increased walking speeds due to downstream pedestrians by choosing to pass, or overtake, such obstructions. It is hypothesized that the decision to pass a downstream obstruction is a function of the locations of the obstructions along the walkway. This is because it is the location of the downstream obstruction that affects the increase in a pedestrian's travel time. Thus, for example, an observer would expect to see a higher incidence of passing near the entrance of the walkway, where the travel time savings as a result of passing are the greatest. Ongoing research, based on the findings of this study, is investigating this issue.

MOTIVATION FOR FURTHER RESEARCH

The results found in this study provide insight into the walking speeds of airport pedestrians under various conditions, including

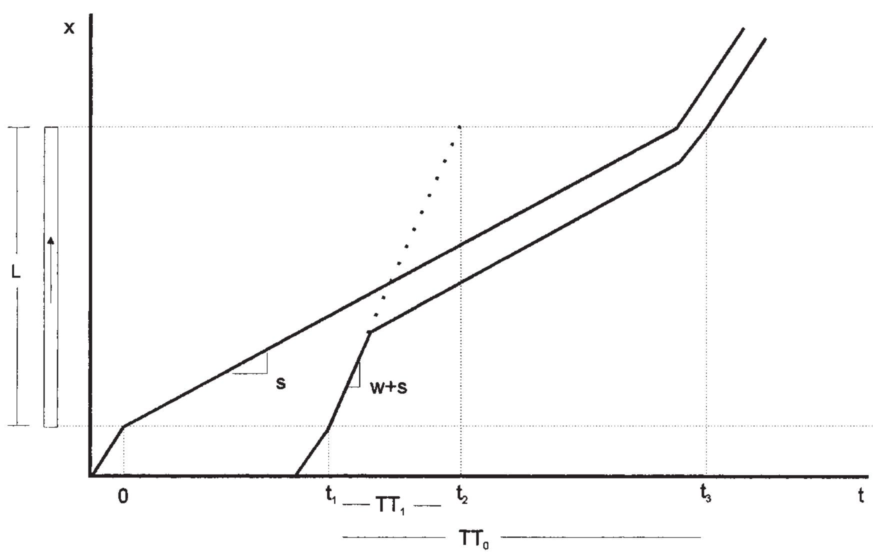

FIGURE 7 Single downstream obstruction.

TABLE 3 Effect of Passing Downstream Obstructions on Average Walking Speed

Obstructions passed	Percent of walkers	Average walking speed
ALL	20 %	204 ft. / min. (62.2 meters/min.)
NONE or SOME	80 %	125 ft./ min. (38.1 meters/min.)

whether or not moving-walkway systems are present. This motivates an examination into the relative benefits of such systems. While this study is certainly a necessary component toward such an examination, additional analysis must be performed to ultimately determine the benefits of moving walkways. Most importantly, a pedestrian's *choice* on using a moving walkway, based in part on the expected travel times on and off the walkway, must be investigated. Ongoing research is focused on the development of a model that will yield more definitive insight into the benefits of such systems.

CONCLUSIONS

Although significant investment has been made to install automated pedestrian movement systems within airport terminals, little is known about their effects on airport pedestrian flows. Specifically, while walking speeds of pedestrians have been studied in general, such analysis specific to airport passengers is lacking. This study provides new insight into the walking speeds of airport pedestrians. Considered in the study are corridors with and without moving walkways, which are the common airport automated pedestrian movement systems.

Empirical observations of pedestrian movements in various airport terminal corridors found that there is no significant difference in the mean walking speeds of pedestrians within airport terminals from those of pedestrians in other transportation facilities. Similar to those of other facilities, observable characteristics of pedestrians were revealed to have no significant effect on walking speeds within airport corridors. There were situations, however, in which airport pedestrians chose to reduce walking speeds, particularly in areas where a travel-path decision was approaching or an information system provided incentive to reduce speed.

The presence of a moving walkway in a corridor was found to affect walking speeds for those passengers who used the system. The distribution of pedestrian free-flow walking speeds while on moving walkways revealed a reduced average walking speed, resulting in overall greater travel times for moving-walkway users. The high variation in moving-walkway walking speeds, including the significant percentage of users who stand while on the walkways, results in congestion on the systems, further reducing overall walking speeds. It has been hypothesized that moving-walkway users choose whether to stand, or to walk and pass any number of slower-moving users, based on the locations of such obstructions along a walkway. Further research is investigating this hypothesis.

This analysis may be used to estimate expected travel times in airport corridors and to examine the effects of potential infrastructure investments on such times. The goal of such an analysis is hoped to be that of improving the quality of service at the airport terminal, particularly for the pedestrians who traverse its corridors.

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