Analysis of Moving Walkway Use in Airport Terminal Corridors

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This paper explores the use of pedestrian conveyor systems, otherwise known as moving walkways, in long public corridors such as those found in major commercial airports. The investigation includes a brief comparison of moving walkways with other primary modes of airport terminal passenger transportation and an empirical study of the use of moving walkways through analysis of passenger conveyors at the United Airlines Terminal at San Francisco International Airport. The empirical study investigates the physical characteristics of several conveyors and their locations within the airport terminal. The study also examines the passengers that traverse the corridors where the moving walkways are located. Characteristics of the passengers, along with their "mode choice" of transport along the corridor were recorded. With these data, a brief examination of current passenger use is made, with an emphasis on how travel speeds vary with each mode. In addition, implications are drawn concerning a passenger's mode choice, by means of two discrete choice Logit models. The paper briefly compares the findings from the empirical analysis with similar studies performed in Europe in the 1970s. The comparison determines improvements that have been made since the European studies. Finally, the paper draws some speculations as to how characteristics of passenger conveyors may be altered, in hopes of improving their services and ultimately increasing their niche in the pedestrian transport market.

First proposed over 100 years ago, the moving walkway, or motorized passenger conveyor, has been considered an innovative mode of pedestrian transportation. The first public operational moving platforms carrying pedestrians were found at entertainment complexes (such as the 1893 World's Colombian fair in Chicago) and were considered as novelty items. The first effort to implement a conveyor system solely for the purpose of serious passenger transport occurred in 1904, with a proposal to build a continuous moving walkway subway under 34th street in Manhattan, New York, but was never implemented successfully. Few such systems were actually operational in the United States before 1950, the most successful of them being Cleveland, Ohio's "Rolling Road," which transported pedestrians as well as horse and carriages from the low-lying warehouse district to the downtown, some 20 meters higher in elevation. Virtually all operational moving walkway systems were defunct by the early 1950s.

Modern times have shown a rebirth in the passenger conveyor. The moving walkways, however, have been relegated to particular market niches. Conveyors are now primarily found at indoor facilities such as sporting arenas and auditoriums. Most significantly, they are found in major transportation-oriented facilities, such as rail stations, parking garages, and airports. Airports, in fact, are the most predominant users of moving walkways. Because of the large areas required by aircraft for maneuvering, the large number of pedestrians passing through airports, and the large percentage of those passengers carrying baggage, airports, in theory, are ideal locations for moving walkways.

Airport terminals have had a unique experience with passenger conveyor systems. Over the years, airports have acted as testing grounds for technological modifications to passenger conveyors. In addition, airports have provided unique arenas for competition between passenger conveyors and other passenger-mobility systems, such as electric courtesy carts, people movers, and buses. With each mode's inherent advantages and disadvantages, present conveyor technology has found its niche within the airport terminal environment. This paper will discuss briefly the characteristics that have determined its current limited success and provide insight into how modifications to the passenger conveyor may result in success in more areas of society.

PRESENT DAY PASSENGER MOBILITY SYSTEMS

Airports are ideal locations for pedestrian mobility systems for a variety of reasons. The grand scale of most airport terminals and the need for baggage-encumbered passengers to move long distances quickly creates a demand for enhanced mobility.

Airline hub-and-spoke route configurations have increased terminal sprawl while reducing a passenger's time frame for making connecting flights. Therefore, interchanging passengers must be able to move through the terminal quickly to switch flights. Furthermore, passengers must deal with the long distances associated with large-scale terminal buildings that are continually growing as air traffic grows.

There are a number of pedestrian movement technologies available to airports. Presumably, the primary reason for such technologies is to reduce the passengers' travel times throughout the terminal environment. The four primary technologies in use today are as follows:

- Courtesy carts,
- Buses,
- Automated people movers (APMs), and
- Moving walkways.

Articles by Leder (*1*), Smith (*2*), and Sproule (*3*) present comprehensive reviews of each of the above modes, describing the technology of each mode, performance measures, and inherent advantages and disadvantages. Table 1 compares the four primary transport modes. The advantages, disadvantages, and primary market niches for each mode are described.

Courtesy Carts

Courtesy carts are highly maneuverable, electric powered, rubber tired vehicles that can navigate though a terminal concourse shared

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TABLE 1 Performance Characteristics of Passenger Mobility Systems

Mode	Typical Operating Speed	Headway	Capacity
Courtesy Cart	4 - 8 km/hr.	variable	5 pax/cart 150-200 pax/hr
Bus	16 - 55 km/hr.	5 - 15 min.	15 - 60 pax/bus 500 - 1500 pax/hr
APM	13 - 80 km/hr.	1 - 5 min.	1,000 - 14,000 pax/hr.
Moving Walkway	30 m/min.	none	typical: 5,000 pax/hr.

with pedestrians, furniture, fixtures, and building components with ease. Carts are typically used in three cases.

- To transport mobility-impaired passengers who cannot walk long distances or whose walking speeds are well below normal;
- To transport passengers making close connections when above normal walking performance would be insufficient; and
- To provide organized service over a fixed route.

The flexibility of deployment and scheduling, along with the potential for operation without dedicated building infrastructure are two primary advantages of the carts. The largest disadvantages include unscheduled, hence unreliable, service, the low capacity of the mode, and the potential of corridor gridlock in congested areas. Furthermore, courtesy carts are generally disliked by those pedestrians who do not use the mode, due to their apparent intrusion into the pedestrian corridor, and the potential for pedestrian safety compromises. Courtesy carts can serve an important role in assisting the mobility-impaired and connecting passengers with a time shortage, but they are not viable for significant ridership levels because of their physical design and operating environment.

Buses

Buses are rubber-tired, driver-steered vehicles operating mostly on streets and roads in mixed traffic. At airports they typically operate on terminal frontage and circulation roadways on a nonexclusive basis, providing both scheduled and on-demand service to defined curbside stops that are easily relocated. They are used typically for transporting passengers between major airport facilities, such as between terminal buildings, parking areas, and regional public transit systems.

Some advantages of this mode are its flexibility, relatively low cost, and high capacity. The biggest disadvantage is its observed quality of service. Buses are often considered "uncomfortable," and air passengers with baggage often are unwilling to tolerate either crowds or long wait times. Because of their curbside stops, buses are inconvenient for connecting passenger transportation, and airport congestion keeps service speeds low.

Automated People Movers

An APM is a class of public transit characterized by its automatic driverless control of discrete vehicles operating on exclusive rights-of-way, using a specialized guideway to control the vehicles' path. Because APMs are proprietary systems, many technological features vary between suppliers.

APMs typically have high passenger acceptance because of their outstanding safety and service record. However, these systems have high facility and maintenance requirements. As a result, APMs are best suited to relatively high rider levels over routes longer than 300 meters, although shorter alignments in specialized situations do exist.

Moving Walkways/Passenger Conveyors

The conventional moving walkway is a pedestrian-carrying device on which passengers may stand or walk. Propulsion is provided by a treadway that moves at a constant, uninterrupted speed and offers point-to-point service. Nominal lengths vary from 30 to 120 m. Local building codes often govern maximum lengths on the basis of emergency exit requirements. Treadway widths typically range from 100 cm (most prevalent) to 140 cm. Inclines of up to 15 degrees are possible. Treadway speeds are typically between 25 and 35 m/min. 30 m/min is the typical operating speed. Regard for passenger safety prevents higher operating speeds. The capacity of a moving walkway varies with its environment, depending on the speed of the treadway and the foot speed of passengers, among other variables. Practically, moving walkway systems have been found to have capacities of about 5,000 passengers per hour per direction.

Walkway facilities have their inherent advantages and disadvantages. A moving walkway speed of 30 m/min is considerably lower than the average pedestrian walking speed of 70 m/min. Another disadvantage is the small width of the typical walkway. This is a particular problem in airports where luggage-laden passengers walking on the conveyor wish to pass other luggage-laden passengers standing still on the conveyor. Further disadvantages of the system are the barriers to cross-concourse traffic, the inaccessibility to wheelchair or otherwise mobility-impaired passengers, and the inflexibility of the system. Some advantages of the system include the fact that there are no headway and, hence, no waiting time for service, unless the arrival of passengers exceeds system capacity. The system is perceived to be safe and simple and may be integrated easily into any airport terminal environment. Maintenance of the system is also relatively simple. Careful maintenance planning is required, though, because any system stoppage during periods of terminal activity could cause severe inconvenience and because there is no quick-fix or backup system typically available.

An excellent review of the historical evolution of moving walkway technology, including a description of the three main types of moving walkways in use today (rubber belt systems, cleated pallet systems, and rubber covered pallet systems), may be found in John Tough and Coleman O'Flaherty's book entitled *Passenger Conveyor: An Innovatory Form of Communal Transport* (*4*).

Knowing the inherent characteristics of moving walkways, such pedestrian transport systems appear in theory to fit quite well in the airport environment. Despite this theory, however, little has been studied concerning the use of the conveyors empirically. What follows is one such study. Specifically, a case study of the moving walkways at the United Airlines Terminal at San Francisco International Airport is made, with the goal of determining who uses the moving walkways, how, and when, depending on the characteristics of the moving walkways, the corridors in which they are located, and the passengers that travel the terminal corridors.

ANALYSIS OF MOVING WALKWAYS: UNITED AIRLINES TERMINAL, SFO

Methodology

The United Airlines terminal at the San Francisco International Airport has four sets of passenger conveyors for public use. They are located as follows:

- Between gates 80 and 84, after security check;
- Immediately after security check, before gates;
- Corridor between parking garage and check-in counters; and
- Between gates 84 and 87, after security check.

Conveyor banks 1 through 3 were visited on Sunday, April 24, 1994, between 3:00 p.m. and 6:00 p.m. The following physical characteristics of each conveyor system were surveyed:

- Treadway belt speed;
- The number of belts in each direction;
- "Departure" direction = heading toward the farthest gates;
- "Arrival direction" = heading toward the parking garage;
- The incline of the corridor (in degrees);
- The length of the conveyor; and
- The width of the conveyor belt.

Table 2 describes the observed characteristics of the conveyors.

At the time of the study, the arrival direction conveyors in conveyor bank 2 were closed for maintenance. After recording the above data, observations regarding how each conveyor was utilized were made. At each site, pedestrians were selected randomly for observation on passing a predetermined entrance threshold in the corridor. This threshold was determined to be an imaginary line along the corridor floor perpendicular to the entrance to the conveyor and approximately 5 m before the entrance to the conveyor. This location made it possible to observe passengers who were dedicated to traversing the corridor but had not yet committed to his/her mode of transport. During this time, the following passenger data were collected:

- The passenger's approximate *age*, to the nearest decade;
- The passenger's *sex*;
- Whether the passenger was a *business*- or *leisure*-type traveler; and
- The *number of bags carried* by the passenger.

The above characteristics were made using the best judgment of the observers. Although age and sex characteristics appear clear to assess, passenger *type* may be unclear. Characteristics of the person's attire and type of baggage were the two factors most keenly observed to determine the purpose of the passenger's trip. For instance, an adult in a business suit carrying a briefcase was noted to be a business traveler, whereas a child in casual clothes carrying a teddy bear was noted as a leisure traveler.

The amount of baggage was recorded in the following manner. For the purposes of this study, any item larger than a purse was considered to be a baggage item. No discrimination as to the weight of an item was made. Although the method an item was carried (e.g., over the shoulder, toted along wheels, or lifted) was recorded, analysis later revealed that this characteristic had little effect on conveyor use and was dropped from the study.

As the traveler crossed the conveyor threshold, it was recorded whether (s)he entered onto the conveyor or bypassed it. If the person chose to use the conveyor, it was recorded whether the person stood still and traveled at the speed of the conveyor, or walked along the belt. Finally, the duration of travel from the entrance threshold to the exit threshold was recorded. The exit threshold was defined as an imaginary line where the conveyor belt ends, marking the point where the presence of the conveyor has no bearing on the passenger's travel. This observation defined the three modes of transport along the corridor, STAND, WALK, or BYPASS, and provided complete measurements on the time each passenger needed to traverse the corridor, given his/her mode choice. A total of 269 observations were made during the observation period.

Analysis of Observed Data

Initial analysis of the sample revealed that a vast majority of the sample did use the conveyors in some fashion (i.e., either chose mode STAND or WALK). Of these, approximately one-third of the conveyor users stood still on the conveyor belt. The distribution of mode choice, as well as the average travel speed and travel time of each group of passengers, is illustrated in Table 3.

The most striking results to come out of this initial analysis was that the average travel speed for passengers using the conveyor (STAND/WALK combined) was only marginally higher than for those who chose BYPASS the conveyors. Moreover, the average travel time to traverse the corridors was almost 7 sec higher for those using the conveyors than for those bypassing. These initial results prompted two further forms of analysis, one to further explore changes in passenger foot speed and one to evaluate the mode choice made by passengers.

TABLE 2 Conveyor Characteristics

Conveyor	Speed (m/sec)	# belts (dep.)	# belts (arr).	Slope(°)	Length (m)	Width (cm)
1	0.64	1	1	0	85	100
2	0.64	1	2	0	120	100
3	0.64	1	1	+2° arr.	80	100

TABLE 3 Mode Choice Distribution

Mode	# Sampled	% Total	Avg. Speed (m/sec)	Avg. Time (sec)
STAND	57	21 %	0.67	135
WALK	146	54 %	1.70	59.18
USE	**203**	**75 %**	**1.41**	**80.47**
BYPASS	66	25 %	1.36	73.20

Analysis of Changing Foot Speeds

The above initial observation prompted a deeper analysis of changing walking pace for those using moving walkways. This analysis studies the changing foot speeds of passengers choosing to WALK. The analysis was performed for each conveyor in each operable direction.

For each conveyor in the study, the noted conveyor belt speed and average walking pace for a bypassing passenger were summed together to determine a theoretical travel speed for a passenger who chooses to WALK on the conveyor without changing natural foot speed. This theoretical speed was then compared with the average walking speeds for each location. The results of these calculations are found in Table 4. The results show a decrease in walking speeds ranging from 0.15 to 0.45 m/sec for passengers walking on conveyors. Further analysis, breaking down the sample of passengers into groups according to similar characteristics, revealed no significant departure from the overall decrease in walking speed.

This consistent decrease in walking speeds may be primarily due to the physical characteristics of the conveyor. The narrow width, rubber-belt footing, and belt speed of the conveyor all contribute to passengers slowing their step when walking. Furthermore, the walking speeds tended to be slow for conveyors having a higher passenger flow, and hence higher degrees of congestion.

Mode Choice Analysis

To explore the mode choice made by passengers, analysis was performed by the evaluation of two discrete choice Logit models, each with one independent variable. The first model evaluated the three mode choices (STAND vs. WALK vs. BYPASS) using the independent variable travel speed. The second model evaluated the same choices using the independent variable, travel time, which takes into consideration the length of the corridor traversed.

The Logit analysis was performed using the *ALOGIT* computer software package. To successfully run *ALOGIT*, a proper data set must be used. Such a data file required data that could not be observed directly in the field. Specifically, the travel times and travel speeds for the two modes that a passenger did *not* choose when traversing the corridor could not be observed and recorded. An estimation of these alternative choice attributes was made by the following methodology.

Estimation of Alternative Choice Attributes

STAND

For those passengers who did not choose STAND, the travel speed and travel time values for the alternative STAND were merely calculated as follows:

Travel Speed = Belt Speed
Travel Time = Belt Speed * Length of Conveyor

WALK

For those passengers who did not choose WALK, a linear regression model was applied. The regression was based on those passengers who did choose WALK, and the characteristics of their environment when the choice was made. The specific characteristics included in the regression were as follows:

X_1 = Corridor/Conveyor Length (m). (1a)
X_2 = Belt Speed (m/sec.). (1b)
X_3 = Congestion level of the conveyor (1 = congested, 0 = uncongested). (1c)
X_4 = The incline (slope) of the corridor (degrees). (1d)
X_5 = The age of the passenger (to the nearest decade). (1e)
X_6 = The sex of the passenger (1 = male, 0 = female). (1f)
X_7 = The "type" of passenger (1 = business, 0 = leisure). (1g)
X_8 = The number of bags carried by the passenger. (1h)

(Note: The following analysis was performed using data measured in U.S. units. Resulting formulations were adjusted to metric units after analysis was performed.)

TABLE 4 Changing Foot Speeds, by Conveyor

Conveyor	1 Dep.	1 Arr.	2 Dep.	3 Dep.	3 Arr.
Bypass Speed (m./sec.)	1.34	1.36	1.18	1.60	1.40
Belt Speed (m./sec.)	0.64	0.64	0.64	0.73	0.73
Bypass + Belt Speed (m/sec)	1.98	2.0	1.82	2.33	2.14
Conveyor Length (m.)	85.4	85.4	119.3	79.3	79.3
Est. Travel Time (sec.)	43.08	42.75	65.48	33.97	37.13
Obs. WALK travel time (sec.)	46.97	51.84	88.44	55.00	49.00
WALK + Belt Speed (m./sec)	1.82	1.65	1.35	1.44	1.62
Obs. WALK foot speed (m/sec)	1.18	1.01	0.71	0.70	0.89
Change in foot speed (ft./sec)	**-0.16**	**-0.35**	**-0.47**	**-0.89**	**-0.52**

Table 5 displays the resulting linear regression coefficients that were used to estimate the total travel speed and travel time of the passengers should they have chosen to WALK:

(Note: All regression equations are of form:
$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n$) (2)

Initially, only the travel speed independent variable was considered for regression analysis. Travel time was to be estimated by merely multiplying the estimated speed by the corridor length. Further consideration, however, brought on the hypothesis that the length of the corridor itself may have a significant effect on the travel speed of a pedestrian. This may be most prevalent in those who chose to WALK along the conveyors. Along longer corridors, for example, several passengers were observed to STAND on the conveyor for a portion of the trip, and then begin walking for the duration. To test this hypothesis, estimated travel time data from the above regression equation was compared with simple *time = length * speed* results against true data for those who did indeed WALK. The regression equation did produce a better match to the true data. The results of the simple formula tended to underestimate those whose true travel time was on the high end of the spectrum.

It is interesting to note that belt speed has a negative effect on total travel speed across the corridor. This enriches the above analysis of changing foot speeds when walking on conveyors. Another interesting result of this regression was that the speed increases with increasing numbers of bags carried. One explanation for this may be that those passengers with more baggage tended to be in more of a rush to catch their flights than were those with fewer bags. Other independent variables appear to have intuitive effects on travel speed and time, which further justifies the use of the equations in the estimation process.

BYPASS

For those passengers who did not choose to BYPASS the conveyor, a similar regression analysis was performed to estimate their BYPASS speeds and travel times. The variables used in the regression were those that would have had an effect on their bypass speed or travel time, respectively. Table 6 lists the values that represent coefficients in the travel speed and travel time equations.

Again, it is interesting to note the increase in travel speed and similar reduction in travel time with increasing numbers of bags carried. Other variable coefficients appear more intuitive.

A successful run of *ALOGIT* using the Travel Speed data produced the following utility functions for each mode choice:

WALK: $U_W = 0.7241 + 0.076TS_W$ (3a)
STAND: $U_S = 0.0326 + 0.076TS_S$ (3b)
BYPASS: $U_B = 0 + 0.076TS_B$ (3c)

A few interesting observations may be made from these functions. The most distinguishing characteristic is the positive alternative specific constant in the STAND mode utility function. More importantly, the constant is higher than that of the base mode, BYPASS. This implies that standing indeed may carry a higher utility for those whose normal foot speeds are very close to the speed of the belt. Pedestrians of older ages, as well as those with physical impairments may easily fit this category (it is interesting to note that age was indeed one of the more significant variables in the travel speed regression analysis).

Applying the above utility functions into the Logit model reveals some interesting issues. In comparing two hypothetical passengers with the following travel speed characteristics:

"Healthy"	"Impaired"	
$TS_W = 6.0$ ft/sec	$TS_W = 4.5$ ft/sec	(4a, 4b)
$TS_S = 2.1$ ft/sec	$TS_S = 2.1$ ft/sec	(4c, 4d)
$TS_B = 4.6$ ft/sec	$TS_B = 3.0$ ft/sec	(4e, 4f)

the following utility values are derived:

$U_W = 1.18$	$U_W = 1.07$	(5a, 5b)
$U_S = 0.192$	$U_S = 0.19$	(5c, 5d)
$U_B = 0.349$	$U_B = 0.023.$	(5e, 5f)

Applying these utility values to a Logit function of the form:

$$P(\text{mode x}) = \frac{e^{Ux}}{e^{Ux} + e^{Uy} + e^{Uz}} \quad (6)$$

The following mode choice probabilities are found:

	"Healthy"	"Impaired"	
P(WALK)	0.55	0.57	(6a, 6b)
P(STAND)	0.21	0.23	(6c, 6d)
P(BYPASS)	0.24	0.20	(6e, 6f)

TABLE 5 Regression Coefficients, WALK Alternative

Coefficient	Travel Speed (TS_W)		Travel Time (TT_W)	
α	+ 2.485	(t = 1.22)	+ 54.46	(t = 0.56)
β_1	- 0.003	(t = -0.20)	+ 0.01	(t = 0.05)
β_2	- 1.086	(t = -0.70)	+ 4.79	(t = 0.22)
β_3	- 0.363	(t = -0.22)	+ 35.19	(t = 1.48)
β_4	- 0.17	(t = -1.40)	+ 1.05	(t = 0.60)
β_5	+ 0.005	(t = 0.45)	- 0.28	(t = -1.77)
β_6	+ 0.217	(t = 0.79)	- 4.25	(t = -1.10)
β_7	+ 0.34	(t = 0.90)	- 6.10	(t = -1.13)
β_8	+ 0.178	(t = 0.98)	- 3.44	(t = -1.34)
ρ^2	0.07		0.30	

TABLE 6 Regression Coefficients, BYPASS Alternative

Coefficient	Travel Speed (TS_B)		Travel Time (TT_B)	
α	+1.380	(t = 11.01)	-34.00	(t = -3.75)
β_1	0		+ 0.35	(t = 13.92)
β_2	0		0	
β_3	0		0	
β_4	-0.11	(t = -0.92)	+ 1.64	(t = 1.10)
β_5	+ 0.01	(t = -0.83)	+ 0.04	(t = 0.30)
β_6	+ 0.33	(t = 1.37)	- 1.74	(t = -0.57)
β_7	+ 0.073	(t = -0.23)	- 1.68	(t = -0.42)
β_8	+ 0.212	(t = 1.41)	- 3.69	(t = -1.96)
ρ^2	0.12		0.79	

These probabilities are highly consistent with the proportion of passengers' mode choices in the sample data.

From the similarities in mode choice probabilities, as well as from direct inspection of the travel speed coefficient of 0.076 in the utility functions, it can be inferred that the sensitivity of travel speed to mode choice is quite low. Although in the above comparison the probability of choosing STAND does make the shift to exceeding the probability of BYPASSing, the overall difference in probability values between the "healthy" person and the "impaired" passenger are marginal.

An interesting issue arises when comparing the results of the travel speed model with the travel time model. An *ALOGIT* run successfully made using the above collected data and regression derived travel time values resulted in the following utility function for the three mode choices:

$$\text{WALK: } U_W = 0.932 + 0.01584TT_W \quad (7a)$$
$$\text{STAND: } U_S = -1.287 + 0.01584TT_S \quad (7b)$$
$$\text{BYPASS: } U_B = 0 + 0.01584TS_B \quad (7c)$$

The primary issue to strike the observer when comparing travel time utility functions with the travel speed functions is the magnitude of the difference between the variable coefficients and the alternative specific constants. The travel time model has much higher alternative specific constants relative to the independent variable coefficient, marking a significantly less sensitive variable in travel time. What tends to drive the travel time utility functions are the alternative specific constants, which set an immediate significant utility ranking. WALK is clearly the most preferable mode, followed by BYPASS, and STAND is a distant third choice. Only as travel times for STAND increase with rates significantly higher than for BYPASS and WALK will STAND ever become a preferable choice. This is indeed what tends to happen as the length of the corridors increase, or as conveyors become congested.

It is difficult to decide which of the above Logit models should be used preferably as a basis for any general conclusions about moving walkway utilization. However, the utility functions resulting from each analysis suggest that the travel speed model may be more sensitive to passenger related issues, such as passengers' ages or number of bags toted. Conversely, the relatively high alternative specific constants of the travel time model may better describe mode choice probabilities derived from the inherent physical characteristics of the corridor environment itself.

Shortcomings to the Above Study

It is conceded that the above mode choice analysis does have its share of shortcomings. The most prevalent is the fact that the observation process itself led to a series of biases in the sample.

The fact that sampling was only performed on a Sunday afternoon in April most certainly resulted in a biased sampling of leisure passengers. An additional survey performed during a weekday morning or evening would provide a larger sample of business passengers. It would be prudent to expand the data set to observations over different periods of a week, and perhaps a year, to collect a comprehensive, unbiased, and perhaps time-sensitive data set. In addition, the study may have included several "leisure" passengers who were not passengers at all, but those meeting or seeing off passengers. These people may have behavior patters of their own, which were not recognized in this study and merely were absorbed within the leisure passenger category. Furthermore, observer biases of a passenger's age and travel type are in no way insignificant. A direct response from the passengers themselves would alleviate any prejudices by the observers.

Some elements of the conveyor environment related to the physical environment and to the passenger characteristics were excluded from the survey. Environmental characteristics such as the presence of windows or other displays, or the presence of destinations (such as gates, or other corridors) at locations between the start and end of the conveyor were considered. Passenger group characteristics were also excluded. That is, there is no differentiation between a passenger traversing the corridor alone with one partner, or with a large group, etc. These characteristics are perhaps significant contributors to mode choice in the corridor.

COMPARISON WITH HEATHROW AIRPORT "TRAVELLATOR" STUDY

A study conducted by the Loughborough University of Technology assessed the use of the "travellator" passenger conveyor at London's Heathrow airport terminal 3 in April 1974 (*5*). The purpose of the study was to determine user behavior on the conveyors, much like this study. Their study, however, focused on safety and comfort issues concerning the conveyors. The findings of the study may have resulted in modifications to the design of passenger conveyors, including those at San Francisco's airport.

A preliminary study of user behavior at Heathrow revealed that a significant proportion (nearly 20 percent) of conveyor users had a non-negligible amount of difficulty with the conveyor. Most difficulties related to users losing their balance when boarding or alighting the belt. The loss of balance was primarily due to slight movements or compulsive jerks experienced when boarding. The results of the preliminary study led to a more in depth analysis of the travellator at Heathrow and a comparison to a similar conveyor in France (the Montparnasse travellator).

The Heathrow travellator ran for a length of 110 m in a corridor known as the "pier connector" that connects Heathrow's main terminal with "terminal 3." The conveyors were 1 m wide and were operated at a speed of 0.67 m/sec. Observations of passengers using the conveyor were made by filming pedestrian flows between 6:00 a.m. and 10:00 a.m. This time was chosen to observe peak flows, when large aircraft normally arrive from overseas. Using the film a total of 290 passengers were studied. Similar to our study, the sex, age, and number of bags carried by each passenger were recorded. Furthermore, the approach speed, step length, and boarding speed of each passenger were calculated (by counting travel distance per frame of film); whether the passenger used the conveyor handrail, did a "threshold check" (i.e., adjusted their step length to board the conveyor), and whether the passenger had any problems boarding were all noted.

The studies performed at Heathrow and Montparnasse found that the Heathrow conveyor had considerably more boarding problems (31 percent of sample) than the Montparnasse (20 percent) conveyor. This despite the fact that the Montparnasse conveyor traveled at a higher velocity (0.854 m/sec) than Heathrow's (0.67 m/sec).

The results of the study concluded that the main factor causing conveyor boarding problems was "improper boarding techniques." These techniques mainly involved "over-preparing" to board the conveyor, by altering one's step, grasping for the handrail too early, or looking down when boarding. Their conclusions were supported by the fact that the population of users at Montparnasse were younger, business travelers who were familiar with the travellator, whereas the Heathrow users were older, leisure passengers with less experience on moving walkways.

Whether the Loughborough conclusions are plausible or not, some of its recommendations for conveyor improvement appear to have been used in modern conveyor systems, including those in San Francisco International. For instance, the moving handrail was determined to be an important aid in maintaining one's balance when boarding the conveyor. Extending the handrail beyond the entrance threshold would help passengers to judge the speed of the system so that boarding could be accomplished more successfully. The width of the conveyor was determined to affect the ease of use as well. Conveyors that were too narrow often led to easily obstructed passageways, leaving less sight and, hence, less preparation for boarding. The study suggested that the width of the conveyor be increased to at least 1 m. Finally, the addition of instructional signs such as "Keep Walking when Boarding" were suggested.

The study suggested that these improvements along with the increased experience the public has with passenger conveyor would reduce the amount of passenger difficulties. During the course of the SFO study, no passengers were observed to have any difficulty with the conveyors. Although there were no instructional signs evident, the handrails were extended from the entrance threshold, the conveyor was wider than the Heathrow travellator and, probably, the passengers observed were more familiar with moving walkways.

CONCLUSION

In the above analysis of pedestrian mode choices throughout the United Airlines terminal at San Francisco International, we hope to provide some insight into who uses passenger conveyors, how, and why. By looking at the characteristics of the corridors themselves and the passengers who traverse the corridors, discrete choice models based on travel times and travel speed were made. In addition, the phenomenon of passengers changing foot speed was studied briefly.

The results of the analysis, although questionable in their statistical significance, do provide some insight into the use of passenger-moving walkways. It is shown that the vast majority of passengers use the conveyors in some manner. Those who use them tend to WALK along with the conveyor belt, rather than STAND still. There are suggestive relationships among passenger characteristics, environmental characteristics, and mode choice. The analysis suggests that looking at a travel speed based model is recommended when analyzing mode choice on the basis of passenger characteristics and that a travel time-based model is preferred when looking at issues of the physical corridor environment itself.

The above results lead to the implication that the passenger conveyor has become a popular mode of transportation not by reducing passenger travel time, but by acting as a convenience for those passengers who wish to slow their walking pace or stand still while traveling the corridor. For this reason, moving walkways have found a solid niche in airports for those routes with insufficient pedestrian density to warrant other modes, such as APMs, but sufficient lengths to preclude walking. Since the Heathrow study, moving sidewalks have appeared in more locations and have been improved, and as a result the public seems to be comfortable with their use. However, because moving walkways are perceived presently as a convenience rather than a necessity, their full potential may not be realized fully. It would be beneficial to passengers if moving walkway systems were developed that could capitalize on the low cost and convenience of use without having to pay the price currently associated with the mode's shortfalls, such as slow belt speeds, narrow belt widths, and one-destination limitations. Airport terminals would serve as excellent test-beds for conveyor improvements in the above areas. Terminals have a continual supply of unfamiliar system users. Also, systems easily can be tested in a short-distance configuration before full-scale installation. This ideal situation should encourage terminal designers to research any new developments in the moving walkway arena and to consider seriously installing cutting-edge systems that could outperform current technology.

With the above methods described in this empirical study and the above technical considerations, authorities considering the installation or modification of airport corridors with passenger conveyor systems may gain further insight into their potential investments. Such insight may also lead to the proliferation of the passenger conveyor, or moving walkway, further into the realm of pedestrian transport.

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