# Review of Four Alternative Airport Terminal Passenger Mobility Systems 

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#### Abstract

United States air travel is expected to grow at high rates for at least the next decade. In 2001 there will be 807 million passengers annually, compared with 400 million in 1985. As airport terminal facilities continue to increase in size, airport planners, designers. and operators will place more reliance on passenger mobility technologies to provide an acceptable level of service to both transferring and origin-destination travelers. Four such technologies are revicwed: moving sidewalks, courtesy calls, buses, and automated people movers. Examples of installations at U.S. airports are discussed. Salient features, including advantages, disadvantages, and limitations, are identified. A set of generalized system performance criteria are presented for use as a checklist by airport planners and designers. Conclusions about the applicability of each technology are included.


The growth during the past decade in United States air transportation is expected to continue into the 21st century. In 1980, 316 million airline passengers used U.S. airports. The Federal Aviation Administration forecasts that by 2001, annual U.S. airline passengers will reach 807 million, an increase by a factor of 2.6 in 21 years. The growth trend is shown in Figure 1. Planners, designers, and operators of airports, as well as the airlines, face substantial challenges in facilitating such remarkable increases in activity.

A consequence of the massive growth in air travel is that the scale of modern airport terminals often exceeds human proportions. To achieve designs with acceptable passenger walking distances and aircraft-to-aircraft transfer times, more reliance is being placed on technology. General increases in air transport activity and the development of airline connecting hubs have made and will continue to make passenger mobility within and between terminals a more important part of terminal planning and design.
The following passenger mobility technologies are reviewed in this paper: moving sidewalks, courtesy carts, buses, and automated people movers (APMs). Each of these technologies is used today at airports in the United States and foreign countries.

Before examining the four mobility technologies in detail, the question of why airport terminals nced to be built on such a grand scale will be discussed.

## AIRLINE OPERATIONS

To start with, airplanes are, in themselves, large. To illustrate that point, wingspan and maximum length for the range of

[^0]common commercial transport aircraft in use today are given in the following table:

|  | Capacity <br> Aircraft Type | (passengers) | Wingspan (ft) |
| :--- | :--- | :--- | :--- | Fuselage Length (ft)

Because of the large size of aircraft, apron frontage dimensions associated with terminal buildings must be substantial.
In addition to the size of aircraft, the total frontage requirement depends on the fleet mix (relative proportion of aircraft types) and number of aircraft that must be simultaneously accommodated. Thus, a lot of terminal frontage is required to park and service a large number of modern commercial transport aircraft at the same time.

## Connecting Hubs

After federal deregulation of air carrier competition, airlines generally abandoned their traditional point-to-point route structures in favor of hub-and-spoke configurations. Hub airports, besides serving origin-destination travelers, are used as transfer nodes where as many as 60 to 70 percent of the passengers only make connections from one flight to another. Aircraft from spoke origins arrive, passengers are exchanged, and the aircraft then depart for spoke destinations. That process is referred to by the airlines as a connecting bank. As many as 8 to 10 connecting banks may occur each day at a large hub. These banks produce significant peaks in activity separated by periods when there are not many aircraft or passengers at the terminal.
For an airline hub to function efficiently, passengers arriving on any given flight must be able to transfer to every other flight in the connecting bank. Therefore, all aircraft in the connecting bank must be parked at the terminal simultaneously. That is the requirement that leads to the terminal sprawl associated with large hub operations.
The airlines are interested in completing the connecting process as quickly as possible to maximize the productivity of their aircraft fleets. They schedule as many connecting banks as possible during the time of day that passengers desire to travel. Table 1 gives minimum on-line connecting times for six large hub airports to illustrate that point. Minimum connecting times, which are published in the Official Airline Guide, are used by airlines and travel agents in constructing passenger itineraries. The minimums become facility maximums from the viewpoint of terminal planners and designers.


FIGURE 1 United States airline passenger growth.

TABLE 1 MINIMUM DOMESTIC ON-LINE CONNECTING TIMES (MINUTES)

| AIRPORT | HUB AIRIINE | TTME |
| :---: | :---: | :---: |
| Dallas-Fort <br> Worth | American | 30 |
|  | Delta | 30 |
| Denver <br> Stapleton | United | 25 |
|  | Continental | 25 |
| Atlanta Hartsfield | Delta | 35 |
|  | Eastern | 30-35 (a) |
| Chicago O'Hare | United | 29 |
|  | Anerican | 25-40(b) |
| Detroit <br> Metropolitan | Northwest | 30 |
| Charlotte Douglas | U.S. Air | 30 |

(a) Depends on gate location
(b) 40 minutes if widebody aircraft is involved.

Source: Official Airline Guide, North American Edition, July 1, 1990, Vol. 16, No. 19.

## Origin-Destination Passengers

Although much emphasis is currently placed on connecting passengers, there are large numbers of passengers who want to go to or from hub cities. They too must confront the great distances and times associated with hub terminals.

Other airports, without the high level of connecting passengers associated with the hubs, tend to be more origindestination oriented. Many of them, because of general growth in air travel, have large-scale terminal facilities with long walk-
ing distances that consume substantial time. Some large airports that serve a high percentage of origin-destination travelers are Boston Logan, Las Vegas, New York La Guardia, Orlando, Seattle, Tampa, and Washington National.

## Critical Reasons for Passenger Mobility Technology

The preceding discussion indicates that there are two critical reasons for the increased use of technology to aid passenger mobility within and between terminals. They are (a) continued vigorous growth in all categories of air travel for at least the next decade and (b) airline hubbing, which requires the transfer of large numbers of connecting passengers over long terminal distances in a short time.

## ALTERNATIVE SYSTEM DESCRIPTIONS

## Moving Sidewalks

The conventional moving sidewalk is a passenger-carrying device on which passengers may stand or walk. The passenger carry surface (treadway) moves at a constant, uninterrupted speed. Service is point-to-point along a straight line.
Nominal lengths vary from 100 to 400 ft . Local building codes often govern maximum lengths on the basis of emergency exit requirements. Treadway widths typically range from 39 to 55 in ., with the $39-\mathrm{in}$. width predominating. Constant slopes up to 15 degrees ( 27 percent) are possible.

Moving sidewalk speeds are adjustable between 90 and 120 $\mathrm{ft} / \mathrm{min}$. A speed of $100 \mathrm{ft} / \mathrm{min}$ is typical. Suppliers do not recommend higher speeds because of safety concerns. If passengers walk on the moving sidewalk at $230 \mathrm{ft} / \mathrm{min}$, the resulting cumulative speed is $330 \mathrm{ft} / \mathrm{min}$. A discussion of pedestrian walking speeds is provided by Fruin (1).
Moving sidewalk system capacity is a function of speed and passenger density on the treadway. For a $39-\mathrm{in}$. treadway width, a speed of $100 \mathrm{ft} / \mathrm{min}$, and $2.5 \mathrm{ft}^{2}$ per standing passenger, the calculated ideal system capacity is 7,800 passengers per hour per direction. Some suppliers suggest that higher capacities with greater passenger densities are achievable. However, $2.5 \mathrm{ft}^{2}$ per passenger, especially if luggage or other carry-on articles are included, is considered to be a practical minimum (unpublished data, Lea + Elliott, 1988). Given slight pauses in the boarding of moving sidewalks and greater space allocations for those who walk rather than ride, practical maximum system capacity is about 5,000 passengers per hour per direction.

## Courtesy Carts

Battery-powered, electrically propelled courtesy carts are used in many airline terminals for the transportation of passengers. These rubber-tired, driver-steered vehicles are supplied by the manufacturers of golf carts.

Cart capacity ranges from five to about nine passengers with carry-on articles plus driver. Maximum speed is approximately 9.5 mph . However, practical safe operating speed in a terminal environment is usually considerably less-about 3
to 5 mph (on the basis of field observations by Lea + Elliott staff). Operational endurance between out-of-service periods for battery recharging varies widely depending on usage. A full battery recharge requires 8 to 12 hr .

Courtesy carts, which are highly maneuverable, do not operate in an exclusive right-of-way. They typically share the terminal concourse floor with pedestrians, stopping as needed for passenger boarding and deboarding. The drivers maneuver their vehicles to avoid pedestrians, furniture, fixtures, and building components such as doors and partitions.

Service is provided in two ways. Carts are usually used to accommodate (a) mobility-impaired passengers who cannot walk long distances or whose walking speeds are well below normal and (b) passengers making close connections between flights, when even above-normal walking performance would not be sufficient.

Cart service is provided on a more organized basis over a defined route in at least one case. American Airlines uses a flcct of 16 carts in its east side teminial complex at DallasFort Worth International Airport. That operation will be discussed in more detail later in this paper.

## 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, sharing the right-of-way with other automotive vehicles. However, an exclusive right-of-way or dedicated high-occupancy vehicle lane may also be used. Curbside stops are defined but can easily be changed, and either scheduled or on-demand service is provided.

Speeds are influenced by roadway design, dwell time at the stops, and traffic congestion. Because of the relatively low speed performance of airport roadways, vehicle design is usually not a constraining speed factor. Vehicle capacity for buses in airport service is within a nominal range of 15 to about 60 passengers. Most buses are powered by diesel engines.

System capacity, which is a function of headway (time interval between buses) and individual bus capacity, can vary widely from a few hundred to about 1,500 passengers per hour per direction.

## APMs

An APM is a class of public transit characterized by

- Automatic (driverless) control,
- Discrete vehicles that operate on exclusive rights-of-way and have nominal capacities of 10 to about 100 passengers,
- The use of a guideway to control the path of the vehicles,
- Maximum speeds of 8 to 50 mph , and
- System capacities ranging from 1,000 to 14,000 passengers per hour per direction.

Moving sidewalks, escalators, and elevators, although sometimes referred to as people movers, do not fit the foregoing description.

APMs are proprietary systems, and many technological features, such as propulsion, suspension, and control subsystems, vary considerably between suppliers.

Four types of APM configurations, shown in Figure 2, are usually considered for airport applications:

1. Single-lane shuttle: One train moves back and forth on a single guideway lane. The train reverses direction at each end-of-line station.
2. Dual-lane shuttle: There are two independent guideway lanes. One train on each lane moves back and forth, reversing direction at each end-of-line station. To provide the highest level of service, the train movements are synchronized.
3. Bypass shuttle: There is a single guideway lane with a short dual section to allow trains to pass each other. Two trains move back and forth, reversing direction as explained above.
4. Pinched loop: Two parallel guideway lanes connected at each end by crossovers form a collapsed loop. Trains cross


FIGURE 2 APM configuration concepts.
from one guideway lane to the other and reverse direction. The loop configuration permits more than two trains to operate at one time. The pinched loop can also operate as a single- or dual-lane shuttle.

Dual-lane shuttle and dual-lane pinched-loop configurations are most common at airports because they offer frequent service, high capacity, and inherent reliability compared with single-lane or bypass configurations.

Figure 2 shows linear alignments. However, APMs operate successfully with horizontal curves with minimum radii of 100 to 200 ft .

## MOVING SIDEWALKS

As discussed previously, moving sidewalks provide point-topoint transportation along straight lines at low speeds. A good moving sidewalk application is in the United Airlines terminal at San Francisco International Airport. The layout is shown in Figure 3.

The $100-\mathrm{ft} / \mathrm{min}$ tread speed compares poorly with maximum pedestrian walking speed, which is approximately $230 \mathrm{ft} / \mathrm{min}$. If it is assumed that passengers walk on a moving sidewalk, the cumulative speed is $330 \mathrm{ft} / \mathrm{min}$. However, moving sidewalks with standard $39-\mathrm{in}$. tread widths do not perform well with mixed standing and walking traffic. This limitation is especially significant in an airport environment because of luggage or other carry-on articles that most passengers have with them. For standees, these items are typically placed on the moving sidewalk tread next to the passenger. They make passing maneuvers by walkers, many of whom also have carry-


FIGURE 3 United Airlines concourse, San Francisco International Airport.
on articles or luggage in their hands or on their shoulders, difficult
The approximate trip time to cover the $1,450 \mathrm{ft}$ from Point A in the main terminal to Point B at the most remote United gate (see Figure 3) is 11.3 min if passengers do not walk on the moving sidewalk. That value was calculated by using 100 $\mathrm{ft} / \mathrm{min}$ moving sidewalk speed and $230 \mathrm{ft} / \mathrm{min}$ walking speed. Associated walking distances are significant. Of the total 1,450ft trip, about 560 ft ( 39 percent) is walked.

With moving sidewalks, access is continuous over time. Thus, frequency of service is not a factor unless there is a queue at the entry point, where passengers briefly pause when making the transition to the moving treadway.

Because the moving sidewalks are located on the concourse level and are a prominent linear element, oriented in the direction of travel, wayfinding is straightforward. The use of two moving sidewalks operating in the same direction in the connecting corridor between the main terminal and the concourse requires simple signs to explain usage.

As mentioned, luggage or carry-on article accommodation on moving sidewalks is a disadvantage in a walk left, ride right setup with the 39 -in. tread width at San Francisco and in common use at other airports. Operation of parallel moving sidewalks in the same direction, as in the United connecting corridor, allows segregation of those wishing to walk and those wishing only to ride.

Persons in wheelchairs and most other mobility-impaired passengers are not able to use moving sidewalks. Some alternative form of transportation must be provided.

At operating speeds of $100 \mathrm{ft} / \mathrm{min}$, moving sidewalks are perceived as being safe by almost all passengers. Because they are in plain view on the concourse level and lengths are limited by building codes, security is not a problem.

As is evident from Figure 3, moving sidewalks, because of their orientation and point-to-point nature, can be an inconvenient barrier to cross-concourse pedestrian movements. It is often necessary to walk around the end of a moving sidewalk and backtrack to one's destination. This feature is a particularly significant disadvantage at a connecting hub.

Architectural and structural integration into the terminal building is straightforward. It is good design practice to increase concourse width to take into account circulation space displaced by the moving sidewalk units.

Moving sidewalks are not flexible. Access points, locations, and lengths cannot be changed without major reconstruction and its attendant problems of interference with ongoing terminal operations.

Maintenance of moving sidewalks is not complex but does require careful planning. Routine and preventive maintenance is best accomplished at night, when the units can be taken out of service with minimal inconvenience to passengers. Any system stoppage during periods of terminal activity can cause major inconvenience to passengers, who must walk long distances unless there is a parallel unit operating in the same direction.

## COURTESY CARTS

As discussed earlier, courtesy carts are used in two ways. They are most frequently provided on demand for the movement
of mobility-impaired passengers whose walking capabilities are severely restricted and for other passengers making close connections. The services are almost always prearranged with and provided by the airlines or, in some cases, the airport operator.
This highly specialized service involves relatively few carts. They operate in mixed traffic with pedestrians on the aircraft boarding-deboarding level of the terminal. Because there are not many carts, traffic conflicts are not a serious problem. The carts are operated by airline or airport personnel assigned to furnish special services to passengers.
The second use of carts is a unique application in the American Airlines east side terminal complex at Dallas-Fort Worth International Airport. Figure 4 shows the layout of Terminals 2 E and 3 E , which are linked by a narrow connector building. The length of these facilities from the north end of Terminal 2 E to the south end of Terminal 3 E is $6,100 \mathrm{ft}(1.15 \mathrm{mi})$. During connecting bank operations, approximately 12 carts are deployed to transport connecting passengers between arriving and departing flights. Although mobility-impaired passengers and others with close connections are given priority, cart service on a space-available basis is provided to anyone who wants it.
The circulation pattern followed by the cart drivers is based on the destinations of the passengers. Thus, from a system viewpoint, routes are random. However, an attempt is made to distribute the carts so that service to and from all gates is provided on a reasonably uniform basis.

There are no defined boarding or deboarding locations. Passengers access the carts much like roving taxis and are dropped off at their departure gates through notification to the driver.

On the basis of observations made by Lea + Elliott in 1988 with the assistance of American Airlines staff, the average system speed is between 3 and 5 mph . Using 4 mph as the average system speed and assuming steady-state cart flow from one end of the east side terminal complex to the other, cart headway is 2.9 min , producing a system capacity of only 187 passengers per hour per direction. Because of the stochastic nature of the cart system, frequency of service and system capacity calculations on a steady-state basis do not represent the actual quantity of service provided.

Cart service is not as reliable as other passenger mobility technologies that operate on a continuous or regularly scheduled basis. Obtaining a seat on a cart is similar to finding a vacant taxi during a peak period in the central business district of a large city.
Although passengers willingly use the carts, they are not popular. Nonusers often become annoyed with the carts during periods of congestion. The cart drivers compete for floor space with pedestrians. Because cart operations conflict with pedestrians, they create a significant safety risk.

Carts require no special building components other than parking places and sufficient electric circuit capability for battery recharge.
Like taxis, carts are flexible. Because there is no dedicated infrastructure, they can be deployed in a variety of ways and locations to meet passenger demands. Ability to accommodate growth in activity is, however, limited. Cart saturation is reached quickly, given pedestrian congestion on the shared terminal floor. Even with 12 operational carts in the 6,100ft -long terminal complex, pedestrian-cart gridlock has been observed during busy periods.
American Airlines recognizes the limitations and disadvantages of the cart system. A program is under way to replace this stopgap measure with an upgraded APM, the AIRTRANS System, which currently operates in a right-ofway below the concourse level.
American also offers, as an alternative, bus service between Terminals 2E and 3E. The buses operate on terminal frontage and airport circulation roadways. Pickup and drop-off points are at the upper level terminal curb.

## BUSES

Buses have been used at Honolulu International Airport for the past 27 years to transport passengers and employees. As shown in Figure 5, three separate terminals serve overseas, interisland, and commuter passengers. The Overseas Terminal consists of the Main Overseas Area, Diamond Head Concourse, Central Concourse, and Ewa Concourse.
The airport's Wiki Wiki Bus System is used to transport


DISTANCE FROM A TO $B=6,100$ '
40 AIRCRAFT PARKING POSITIONS


FIGURE 4 American Airlines east side terminal complex, Dallas-Fort Worth International Airport.


FIGURE 5 Wiki Wiki bus routes, Honolulu International Airport.

1. Arriving international passengers to the International Arrivals Building for border-crossing functions, including immigration, customs, agriculture, and public health (these passengers must remain separated from domestic passengers);
2. Arriving domestic passengers;
3. Connecting passengers; and
4. Departing passengers.

There is a complex series of routes involving mostly exclusive right-of-way on the landside and some apron level operations for hardstand aircraft positions. These routes are generally shown in Figure 5.

Wiki Wiki buses are specifically assigned to meet each arriving international and overseas domestic flight. By prearrangement, sufficient bus system capacity is allocated to match the number of deplaning passengers, all of whom must proceed to the FIS.

The other bus services are provided on a scheduled basis. The frequency of service depends on the time of day and demands placed on the system by international arrivals.
In 1988 the Wiki Wiki buses carried 5.3 million passengers, which was about 25 percent of total enplanements and deplanements for that year. Thus, the system is used extensively and is an integral aspect of the terminal complex.
An interesting feature of the Wiki Wiki buses is their ability to operate singly or in trains of up to three units. Currently there are 15 powered units and 21 trailers. Vehicle capacity is given in the following table:

|  | Passengers |  |
| :--- | :--- | :--- |
| Description | Seated | Standing |
| Powered unit | 17 | 13 |
| Trailer | 23 | 17 |

The total Wiki Wiki work force is composed of 67 persons, including 54 drivers. The fleet, routes, and number of stops have all increased as the airport has grown.

There is a wide disparity in the level of service. Arriving international and domestic passengers experience short waiting times because the buses meet their flights. On the other hand, interisland and other passengers experience a low level of service with long waiting times of as much as 20 min and circuitous routes.

The buses are not air-conditioned, and ride quality is similar to a city bus, with many starts, stops, and curves. In general, passenger comfort is low, especially when the buses operate at or near capacity. Many passengers, particularly those who are transferring or originating at Honolulu, choose to walk rather than use the Wiki Wiki buses.

## APMs

APMs are currently in use at eight airports in the United States. Seven U.S. airport APMs are in various phases of system design, procurement, and implementation (2).

The APM currently being implemented at the new Denver International Airport is an excellent example of how this technology can be used when long distances are involved. Figure 6 shows the planned layout of the terminal facilities when the airport reaches its ultimate capacity of 55 million annual enplanements. An underground APM, operating in a pinchedloop configuration, will link the main terminal and the four airside concourses with each other. The distance from the center of the main terminal to the APM station in Concourse D , the most remote airside concourse, is $6,600 \mathrm{ft}$. The longest


FIGURE 6 Automated ground transportation system, Denver International Airport.
passenger trip, from one end of Concourse $D$ to the center of the main terminal, will be $8,600 \mathrm{ft}(1.63 \mathrm{mi})$.

The APM will provide a high level of service to passengers, visitors, and airline and airport employees. Ultimate system capacity will be 12,900 passengers per hour per direction. Eight trains will operate on headways of 1.83 min . The maximum trip time from the main terminal to airside Concourse D (if the passenger just missed a train at the main terminal and therefore must wait one headway) will be 7.3 min . Average trip time (passenger waits one-half headway at main terminal station) will be 6.4 min .
The APM system design will provide a high level of reliability through the following features:

1. System component reliability and redundancy,
2. A sufficient number of spare vehicles to allow a comprehensive scheduled maintenance program,
3. Dual-lane guideway with end-of-line and intermediate crossovers to permit continued reduced-service operations should a train or guideway component become disabled for a prolonged period, and
4. A continuously available "hot standby train" that can replace a disabled train on short notice.

Passenger acceptance of airport APMs is generally high. The systems are fully accessible to the handicapped.

APMs have an outstanding safety and security record. Passengers perceive the systems to be safe and secure. Security features include on-board two-way voice communication between passengers and central control operators and CCTV on station platforms.

Because APMs operate in exclusive rights-of-way, vertical circulation requirements associated with stations are a significant facilities design feature. Both static and dynamic signs are typically used to aid the passenger wayfinding process.

An APM requires an exclusive right-of-way, stations, wayside equipment rooms, a central control area, and vehicle maintenance facilities. Most APMs are located on overhead structures or below grade in tunnels. Thus, significant facilities are associated with APMs, and attention to integration with other terminal elements and functions is an important consideration.

Many airport APMs are designed for future expansion. For example, the dashed lines on Figure 6 show how the Denver International terminal facilities and APM guideway will be expanded to include a fourth airside concourse. However, without adding guideway or stations, capacity can be increased by adding cars to trains and decreasing headway to a practical minimum of 90 to 100 sec . At Denver International, the initial system capacity of 6,000 passengers per hour per direction can be increased to 8,300 passengers per hour per direction by changing from two- to three-car trains.

Likewise, capacity can be decreased by using fewer trains at increased headway or by operating trains with fewer cars. At Denver International, fewer trains will be operated during late night and early morning hours, when ridership is expected to be only a small fraction of the peak requirement.

APM systems require a high level of maintenance. Through careful planning of facilities and operations, maintenance can be accomplished without affecting service. The ability of APMs to run at reduced levels of service assists in system maintenance.

## SYSTEM EVALUATION CRITERIA

The previous sections have identified salient features of the four passenger mobility technologies, including advantages, disadvantages, and limitations. In this section evaluation criteria will be organized in an outline. The criteria can serve as a useful checklist for planners, designers, and operators of airport terminals who have responsibility for analyzing and making decisions about passenger mobility systems.

## System Performance

The following performance criteria can be used to measure the functionality of the technologies:

1. Time consumed by the passenger in using the system, which is a function of the speed of the technology and other operating characteristics;
2. Frequency of service, also referred to as headway;
3. System capacity, usually measured in passengers per hour per direction; and
4. Reliability of service, a measure of system dependability.

## Passenger Acceptance

Passenger acceptance, a key consideration, can be evaluated by using the following criteria:

1. Associated walking and vertical circulation requirements (vertical circulation includes stairways, elevators, and escalators);
2. Passenger wayfinding, accomplished through architecture and signs;
3. Luggage accommodations;
4. Use by handicapped persons;
5. Safety; and
6. Security.

## Facilities Interfaces

Passenger mobility technologies cannot be considered as isolated systems. They must interface with the terminal buildings and related infrastructure. Evaluation criteria consist of

1. Constructibility,
2. Architectural and structural integration with other terminal components, and
3. Impacts on other terminal functions.

## Flexibility

Given the dynamic nature of air transportation, assumptions about passenger mobility requirements are often uncertain and temporary. Flexibility criteria consist of (a) expandability to accommodate growth and $(b)$ responsiveness to other changes in conditions.

## Maintenance

Each of the mobility technologies requires varying types of maintenance. The criteria consist of (a) maintenance complexity and (b) impacts on service.

## CONCLUSIONS

Moving sidewalks can be used effectively to aid passenger mobility when the total length of passenger movement does not exceed 1,000 to $1,500 \mathrm{ft}$. The slow treadway speed of 100 $\mathrm{ft} / \mathrm{min}$ and the tendency to form barriers to cross-travel movements are distinct drawbacks. If walk left, ride right use is a serious design goal, either a $55-\mathrm{in}$. minimum treadway width or dual units operating in the same direction are essential.

Moving sidewalks can only provide point-to-point travel along straight lines.

Limited numbers of courtesy carts serve an important role in assisting handicapped passengers and transporting passengers between flights when connecting times are close because of late aircraft arrivals. Because they operate in mixed traffic with pedestrians on the aircraft boarding-deboarding level of terminals, carts are not a viable transportation mode for significant ridership values. Carts should not be operated on fixed routes to transport large numbers of passengers on a regular basis. Carts offer flexibility that moving sidewalks and APMs do not, because they are maneuverable and do not require an exclusive right-of-way.

Buses for transporting connecting passengers between flights have several disadvantages. Because they operate from the terminal curb, they are not convenient. Passengers must pass through anti-air piracy screening on reentry because they leave the sterile area of the terminal. Bus operations involve circuitous routes in relation to passengers' arrival and departure gates. Average speed is low, and trip time is high, because of the shared right-of-way with other vehicular traffic and lengthy dwell times at stops. Poor bus productivity is exacerbated because traffic congestion related to origin-destination passengers occurs during the connecting bank, which is precisely when peak bus activity occurs.
The use of dedicated bus lanes or exclusive rights-of-way displaces valuable roadway space, and, for exclusive rights-of-way, involves high infrastructure costs.

APMs are best suited to relatively high ridership over route lengths in excess of $1,000 \mathrm{ft}$, though shorter alignments in specialized situations should not be ruled out. For example, a shorter APM could be useful to meet high peak ridership when time is critical. APMs offer a high level of schedule and trip time dependability because they use an exclusive right-of-way and their automated operation is not influenced by varying human skill levels associated with courtesy carts and buses.

APMs require careful attention to terminal architecture and structural engineering. Spatial and functional integration into the terminal facilities and related infrastructure is essential.

To effectively meet air travel demands of the 21st century, large airport terminal complexes will incorporate a combination of the mobility technologies discussed in this paper. When designed to act synergistically, these technologies, along with good planning, architecture, and engineering, will result in terminal facilities capable of meeting the challenges that lie ahead.

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