Optimal Configuration of Airport Passenger Buildings for Travelers

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ABSTRACT

This paper uses a novel method of analysis to define the optimal configuration of airport passenger buildings for travelers. The approach explicitly recognizes two significant practical facts omitted in previous work: (1) the importance of transfer passengers, who may comprise 50% or more of the travelers; and (2) the way airlines intelligently position aircraft at gates to minimize the walking distances between connecting flights. The analysis breaks the issue of finding the walking distances of travelers into two parts: (1) an "impedance" matrix that defines the distance or level of difficulty in transiting between any gates, and that results from architectural considerations; and (2) a "flow" matrix that defines the number of passengers going between gates. Multiplication of these matrices results in a "passenger-impedance" matrix that defines the distribution of walking distances or travel time for travelers. Comparison of these distributions shows the relative advantage of different configurations. Results suggest that, from the perspective of the travelers, intelligently managed linear mid-field concourses generally provide the best overall configuration for significant airports passenger buildings.

Key Words: Airports, Passenger Buildings, Configuration, Design, Walking Distances

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INTRODUCTION

Airline passengers typically have to walk great distances in trying conditions. They often have to traverse hundreds of meters, burdened with bags, unable to move quickly because they are either very young or infirm, trying to find their way in a confusing environment and stressed by the pressure of meeting a departure time. Minimization of walking distances is thus an important criterion for the design of airport passenger buildings.

A substantial literature discusses the implications of different configurations of airport passenger buildings for passengers. The older material tends to focus on measuring and minimizing the maximum walking distances. More recent reports have stressed the average distances traveled by passengers, based on even distributions of traffic to the different gates.

Previous formulations tended to ignore two fundamental realities:

- The important role of transfer passengers, who account for a substantial and often dominant fraction of the traffic, and whose walking distances are not anchored to the entrance to the building.
- The fact that airlines and airports minimize walking distances operationally. Managers schedule aircraft at gates to minimize walking distances. They do this to the extent possible

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> by placing connecting flights at adjacent or nearby gates and by docking flights with the most passengers closest to the entrances and exits of the passenger building. In short, intelligent management of the gate assignments makes the average walking distances much lower than they would appear to be from an analysis of the geometry of the buildings.

This paper first presents a novel method of analysis to define the optimal configuration of airport passenger buildings for travelers. This approach uses simple spreadsheets to calculate the performance of possible configurations of airport passenger buildings for any configuration and pattern of flows. It avoids the need to develop and apply detailed probabilistic simulation programs. People with minimal computer literacy can easily develop their own version of the method presented here, based on the information provided. Architects and planners can thus readily use this analysis to evaluate alternative configurations at the initial design stage.

The paper uses this analysis to identify the configurations of airport passenger buildings that appear to minimize the walking distances for passengers most effectively, considering both geometry and intelligent management of the gate assignments. Contrary to traditional guidelines, the results depend significantly on the level of transfer traffic. Moreover, some configurations that appear to minimize walking distances, such as the X-shaped concourses at Pittsburgh, Hong Kong/Chep Lap Kok and Kuala Lumpur/Sepang, turn out to be inferior to linear mid-field concourses similar to those in Denver or Atlanta.

PREVIOUS WORK

Early technical assessments of the relative merits of airport passenger buildings were largely descriptive and impressionistic (R. M. Parsons and ATA, 1973; de Neufville, 1976) as were the later architectural presentations (Hart, 1985; Blow, 1991). Subsequent technical studies calculated the expected walking distances associated with various configurations without transporters. (Using busses to carry passengers to aircraft can minimize walking distances, but this arrangement is expensive and unattractive in many situations because it generally increases the minimum time to connect between the aircraft and exits or transfer aircraft.) Based upon an assumed distribution of traffic from the landside entrance to the airport terminal and the gates, these later studies defined optimal shapes (Wirasinghe et al., 1987; Bandara, 1989; Bandara and Wirasinghe, 1989; Robusté, 1991; Robusté and Daganzo, 1991). The overall conclusion from this later body of work was that finger pier configurations were preferable from the perspective of minimizing walking distances, particularly those with an uneven number of piers featuring a longer central pier that provided close access to the central entrance to an airport terminal.

This previous work did not discuss the implications of transfer traffic on the distribution of walking distances. Indeed the airlines had not yet established the pattern of transfer hubs so prevalent by the year 2000, when transfer passengers represented well over half the passengers at many airports, such as Atlanta, Chicago/O'Hare, etc. (Table 1). Transfer traffic is now often a major factor in determining the walking distances in airport passenger buildings. de Neufville and Rusconi-Clerici (1978) and de Neufville (1995) discussed its importance for the configuration of airport passenger buildings, and de Neufville (1996) presented preliminary calculations of its implications for the choice of configurations.

[Table 1 about here]

Previously published work has not examined the effect on walking distances of intelligent management of the gate assignments. This is however a crucial element in the operations of transfer hubs. Airlines put great effort into insuring that bags transfer along with passengers, and therefore into reducing the "tail-to-tail" distances between aircraft with significant amount of transferring traffic.

Some form of simulation is necessary to explore the implication of different configurations in more depth. It is only possible to determine the performance of these buildings under realistic loads by moving beyond assumed smooth probability distributions. This observation has generated a number of simulation analyses such as those McKelvey (1989) surveyed and Mumayiz (1991,1998) presented

Detailed simulations have not been useful for establishing what configuration to build, even though they are valuable in helping either designers size spaces once they have determined the configuration of the building, or managers to operate a completed building. Detailed simulations are too expensive and take too much time to build and run, to be practical for deciding which of many configurations are best suited for specific situations.

For planning purposes, fairly simple -- and thus inexpensive and rapid -- forms of simulation are needed (Odoni and de Neufville, 1992). Svrcek (1992,1994) developed this idea and proposed a means to analyze the consequences of alternative configurations. At that time, his proposals were difficult to implement in general practice because planners were not routinely familiar with appropriate efficient computational mechanisms. Although the original computer-based spreadsheet program, Visicalc, appeared in 1979 (see www.bricklin.com/visicalc.htm for a history of this process), spreadsheet programs did not become widely available internationally until recently. Simple, rapid simulations are now practical for exploring conceptual designs.

ANALYSIS METHOD

Spreadsheet programs such as Excel ® provide an entirely new way to investigate the effect of the configuration of airport passenger buildings on walking distances. Previously, researchers have used simplistic assumptions about the distribution of traffic to gates so as to obtain estimates of walking distances in reasonable time. Using spreadsheets however, researchers can rapidly analyze the performance of different designs for any distribution of traffic, both between the landside entrances and the gates, and between gates for transfer traffic. Using the “data table” functions embedded in spreadsheets, it is also easy to run parametric analyses for a wide range of conditions.

It is important to stress that the spreadsheet analyses described below require little time to create and run. Anyone familiar with these standard programs can re-create their basic elements in a day or so for any specific airport. In any case, the authors will freely share their models.

The spreadsheet procedure for analyzing walking distances in airport buildings uses two origin-to-destination matrices: the “impedance” and “flow” matrices. The “impedance” matrix defines the level of difficulty in transiting between any gate (or access point to the passenger building) and any other. Most directly, it defines the walking distances between these origins and destinations. It could however represent travel time or some modified measure of distance that accounts for either the benefits of moving sidewalks, people movers or other devices or the inconvenience and delays due to stairways, security checks or other barriers to movement. The “flow” matrix defines the volume of passengers moving between each origin and destination represented in the impedance matrix.

Each of these matrices of basic data captures different aspects of the traffic within the airport passenger building. The impedance matrix describes the physical aspects of the facility. Most immediately, it reflects the geometry of the building. More generally, this matrix incorporates the effects of moving sidewalks, stairs or other interior features to the extent that the measure of impedance accounts for their effects.

The flow matrix on the other hand embodies operational information about the airport passenger building. It accounts for the elements of the issue that were largely left out of previous analyses. Specifically, it reflects

- Transfer patterns, that is the passenger flows from one aircraft to another; and
- Intelligent management of the gate assignments, whereby either airline managers or airport operators place flights with significant transfer traffic at gates close to each other.

The impedance and flow matrices conveniently represent all the basic information on the passenger movements within airport passenger buildings. Their distinct functions facilitate parametric analyses of different issues. Architects for example can investigate the effect of alternative configurations of the buildings for any airport with specific level of transfers. Airport managers can examine the implications of different operational strategies for assigning gates to aircraft.

It is easy to calculate all the interesting statistics on walking distances using these matrices. Multiplying them gives a “passenger-impedance” matrix in which each cell represents the impedance between each origin and destination, weighted by the number of passengers. For example, if the impedance is measured in meters to be walked, each cell in the "passenger impedance" matrix represents the passenger-meters walked by the traffic between the corresponding origin and destination in the building. Summing these results and dividing by the total traffic gives the average walking distance. Sorting the cells by distance, and summing the corresponding passenger-impedances expressed in terms of percent of the total, permits the analyst to develop cumulative passenger-impedance diagrams of the sort shown in Figure 1. These diagrams show the proportion of passengers walking specified distances for any situation. Situations with better performance are those whose cumulative passenger-impedance curve has the most passengers walking shorter distances, that is furthest to the left as the solid line in Figure 1.

[Figure 1 about here]

EXAMPLE APPLICATION OF ANALYSIS

This example shows how the spreadsheet method for calculating walking distances works. It also demonstrates that the average walking distance, when the airport operators allocate the aircraft to gates intelligently so that connecting, originating and terminating traffic is close to their gates, is considerably less than a purely geometric analysis would suggest. The example is excerpted from de Neufville and Odoni (2002).

Consider a short finger pier with four gates and a point of access to the main body of the passenger building. Suppose further that it is 18m (60ft.) wide, that the gates are 60 m (200ft.) apart, and that the access points to the gates are laid out for entry on the left hand side of the aircraft, as in Figure 2. The impedance matrix in meters is then as in Table 2.

This example assumes that each gate is occupied by aircraft with 100 passengers; that there are transfers, particularly between the aircraft at gates 2 and 3; and that the airport operators have intelligently placed connecting aircraft close together. The assumed flow matrix is then as in Table 3. The summations at the right hand side of the flow matrix indicate that each aircraft arrives and departs with 100 passengers, and that 220 passengers enter and exit through the end of the finger pier. This means that 180 passengers transferred on stayed on board their aircraft.

The passenger-impedance matrix resulting from multiplying the two data matrices is then as in Table 4. The totals on the right hand side indicate that the total passenger-meters walked in the finger pier were 42,630. This implies an average distance per person of 68.76m (=42,630/620). This is far less for the conditions assumed than either the maximum possible distance of 129m or the average of 74.67m if there were no transfers.

[Figure 2 and Tables 2, 3 and 4 about here]

APPLICATIONS TO AIRPORT PASSENGER BUILDINGS

The analysis method easily

- explores the implications of transfer passengers and intelligent management on the effective walking distances within passenger buildings: and
- demonstrates which configurations appear best in which circumstances.

The results reported here are for a hypothetical 20-gate passenger building serving large commercial aircraft. The analyses used the following data, which Figure 3 illustrates:

- the distance between adjacent gates is 45.5m;
- distances begin at the face of the terminal, as travel along the airbridge and in the aircraft affects all configurations equally;
- one gate handles 10% of the passenger traffic to reflect the use of this gate for very large aircraft; the remaining 90% is evenly distributed through the other 19 gates;
- for finger piers, the distance between the point of access and the nearest gate is 100m and the very large aircraft gate is located at the far end of the pier;
- for X-shaped concourses, the distance between the center and the nearest gate is 100m and the very large aircraft gate is located at one of the ends of the X;
- linear buildings with one airside were assumed to have three entrances in one scenario – in the middle and at both ends – and only one entrance in the middle in another scenario, to assess the impact of severe security requirements; and
- in linear buildings with one airside and in linear midfield concourses, the gate that handles very large aircraft is located in the middle of the building.

[Figure 3 about here]

Effect of Transfers on Walking Distances: Transfers affect the overall average walking distances within a building. Passengers transferring between flights within the same complex may flow between nearby gates or gates at opposite ends of the building, rather than gates and the entrance to the building. Figure 1 compares walking distances for a linear mid-field configuration of the type in place at Atlanta, Denver, and the United Airline operations at Chicago/O'Hare, assuming no intelligent management. One case assumes that all passengers go between the entrance to the building at its mid-point and the gates. The other case assumes that 60% percent of the passengers transfer to aircraft spaced across the building. As is the case in practice, some of the transfers remain on board the aircraft on which they arrived, because they continue their journey without changing.

Including the transfers in the analysis changes both the averages (denoted as W, subscripted to designate the situation) and the extremes, as Figure 1 indicates. This is as expected since some passengers may have to connect between flights at the very opposite ends of the passenger building. Intelligent management will minimize this phenomenon.

<u>Effect of Intelligent Management on Walking Distances</u>: Intelligent management of the gates simultaneously places

- large aircraft with the most local passengers close to the entrances to the passenger building (this is standard practice at Atlanta and Denver, where the central gates of the mid-field concourses are specifically designed for larger aircraft), and
- aircraft with significant connecting traffic close to each other.

Intelligent management can significantly reduce the average walking distances and the incidence of extreme distances. Figure 4 illustrates these results by comparing the performance of a linear midfield concourse with and without intelligent management of the gates. The intensity of this effect will depend however on the extent to which the airport managers can assign the aircraft to locations that would minimize walking distances. While intelligent management is in principle easy to do for a linear building, it may not be practical for buildings with re-entrant corners or others that limit the location of large aircraft to the far ends of the passenger buildings. Configurations that make intelligent management of gates more difficult include those with finger piers or X-shaped midfield concourses of the type at Pittsburgh, Hong Kong/Chep Lap Kok and Kuala Lumpur/Sebang).

[Figure 4 about here]

Application to Configuration of Airport Passenger Buildings: The analysis was applied to four basic configurations of airport passenger buildings (see Figure 5):

- Linear mid-field concourses (as in Atlanta and Denver);
- X-Shaped mid-field concourses (as at Pittsburgh and Hong Kong/Chep Lap Kok);
- Finger Piers (as at New York/LaGuardia and San Francisco/International); and
- Linear Buildings with only one airside (as at Athens/Spata, Kansas City, Munich, etc.).

These analyses assumed intelligent gate assignment for high and low transfer rates.

[Figure 5 about here]

Linear mid-field concourses minimize average walking distances better than the X-shaped configurations. Comparing buildings serving the same number of gates, the X-shaped buildings of course reduce the maximum walking distance since they spread the gates in four directions rather than two. This advantage is lost, however, when it comes to average walking distances. X-shaped buildings have re-entrant corners at the center. These not only make it impossible to locate aircraft there, but in fact force managers to place larger aircraft towards the ends of the piers. Svrcek (1994) and de Neufville (1996) discussed this effect. Figures 6 and 7 demonstrate the significant advantage of linear mid-field concourses in reducing overall walking distances, both when transfers are high and low. Linear midfield concourses have lower average walking distances ($W_L < W_X$) and more travelers walking shorter distances (curve further to the left).

[Figure 6 and 7 about here]

The relative performance of linear mid-field passenger buildings and finger piers depends on the effort required to transit between the mid-field concourse and the landside, and the number of passengers who are not transferring and must cross this distance. For transfer passengers, either building performs well, to the extent that the managers can cluster the aircraft along the pier or can use a shared lounge area at the end of the finger pier (as at Tokyo/Narita Terminal 1).

(See Figure 8.) For local passengers, the mid-field linear concourse is superior as regards walking distances within the building itself. This is because it enables managers to position large aircraft right at the entrance conveniently located in the middle of the building, and thus to minimize walking between the entrance and the aircraft (see Figure 9). Which of the two configurations is better as regards overall walking distance depends on the importance and discomfort of the travel between the mid-field concourse and the landside.

[Figures 8 and 9 about here]

Linear buildings with one airside and one landside perform well for originating passengers but poorly for transfers. In principle, they minimize the walking distance between the curb and the plane. In practice however, this advantage may be lost because the airport managers may decide to limit the number of access points and thus reduce the cost of security check-points -- as they have at Dallas/Fort Worth for example. When the number of access points to a linear building is limited, the walking distances can be relatively large for any sizeable building.

Transfer passengers in linear buildings with one airside find that, even with intelligent management of the gate assignments, their walking distances are necessarily relatively large. This is because a linear building with one airside is approximately twice as long as it would be if gates were on both sides of the building (as they are in a mid-field concourse or a finger pier). The excessive walking distances for transfer passengers was a prime reason TWA transferred its base of operations from Kansas City to Saint Louis when it set up its hub-and-spoke system with a high percent of transfer traffic. Similarly, Lufthansa decided it had to have a new mid-field building at Munich in order to service its transfer traffic. However, the walking distances for local passengers can be reduced significantly if decentralized facilities are used, including the provision of several entrance points to the building. Figures 10 and 11 illustrate these points by comparing linear buildings with one airside with linear midfield concourses for servicing transfer traffic, and with finger piers servicing local traffic.

[Figures 10 and 11 about here]

SUMMARY

The applications to specific configurations and level of transfer traffic demonstrate the way the proposed method of analysis easily explores the relative advantage in terms of walking distance of different configurations of airport passenger buildings. Table 5 summaries the results, considering both high (60%) and no (0%) levels of transfer traffic. This analysis suggests the advantages of intelligently managed linear mid-field concourses and the disadvantages of finger piers as regards walking distances when intelligent gate assignment is in practice.

[Table 5 about here]

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List of Tables

Table 1. Approximate Transfer Rates at Major Hub Airports In the United States in 1999

Airport (1)	Transfer Rate (%)	
	Airport (2)	Hub Airline (3)
Atlanta	60	70, Delta
Chicago/O'Hare	50	60, American 60, United
Cincinnati	70	80, Delta
Denver	50	65, United
Detroit	50	60, Northwest
Houston/Bush	55	65, CO
Minneapolis/St. Paul	55	65, Northwest
Pittsburgh	55	70, USAir
Salt Lake City	50	65, Delta
Saint Louis	60	75, TWA
Washington/Dulles	30	45, United

Sources: US DOT (2000), Solomon, Smith Barney (2000)

Table 2. Impedance Matrix for Example Application

Node Numbers		O-D Distance (meters)				
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Destination Nodes		1	2	3	4	5
Origin Nodes	1	0	78	108	48	39
	2	78	0	48	48	99
	3	108	48	0	78	129
	4	48	48	78	0	69
	5	39	99	129	69	0

Table 3. Flow Matrix for Example Application

Node Numbers		**O-D Traffic (persons)**					**Row Sum**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Destination Nodes		1	2	3	4	5	
Origin Nodes	1	10	0	0	0	90	100
	2	0	20	10	40	30	100
	3	25	10	20	15	30	100
	4	15	0	0	15	70	100
	5	50	70	70	30	0	220
					Column Sum		620

Table 4. Passenger-Impedance Matrix for Example Application

Node Numbers		**O-D Travel (passenger-meters)**					**Row Sum**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Destination Nodes		1	2	3	4	5	
Origin Nodes	1	0	0	0	0	0	3510
	2	0	0	480	1920	2970	5370
	3	2700	480	0	1170	3870	8220
	4	720	0	0	0	4830	5550
	5	1950	6930	9030	2070	0	19980
					Column Sum		42630

Table 5. Relative Performance of Airport Passenger Buildings assuming intelligent management of gates, in terms of walking distances, when serving high and low levels of transfer traffic (data for 20-gate building)

Configuration (1)	**Average Walking Distance (meters/person)**	
	Transfer Rate High 60% (2)	**Transfer Rate Low 0%** (3)
Mid-field Concourse		
Linear	90	109
X-Shaped	134	136
Finger Piers	202	316
Linear Building, 1 Airside		
3 entrance points:	109	98
1 entrance point:	144	157

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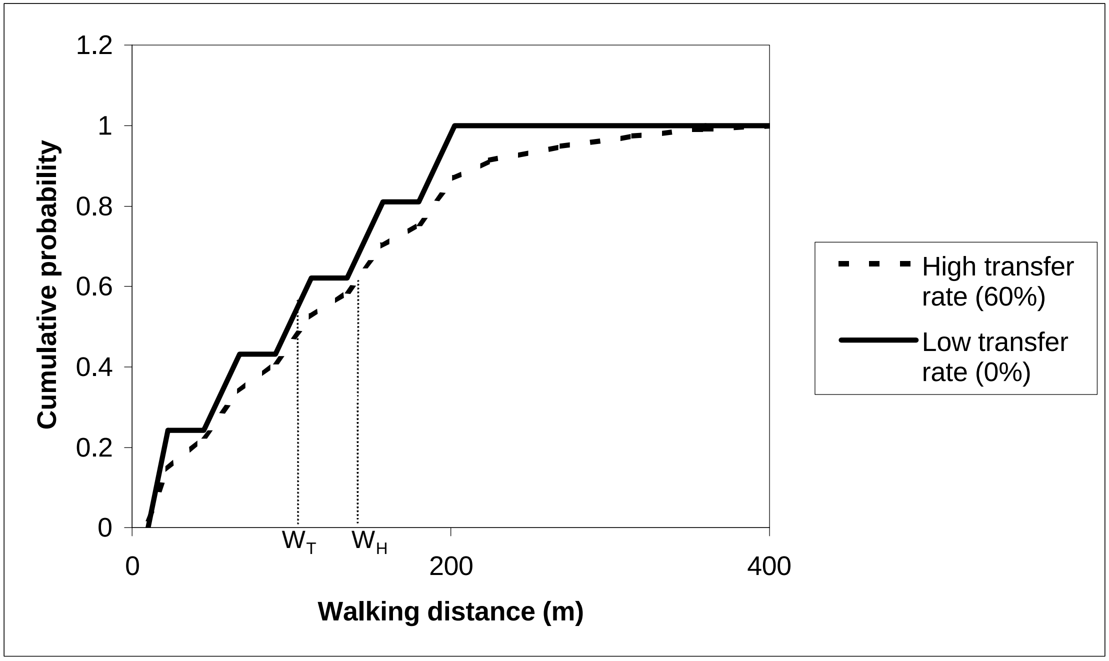

Figure 1: Passenger walking distances in a midfield linear concourse without intelligent gate assignment

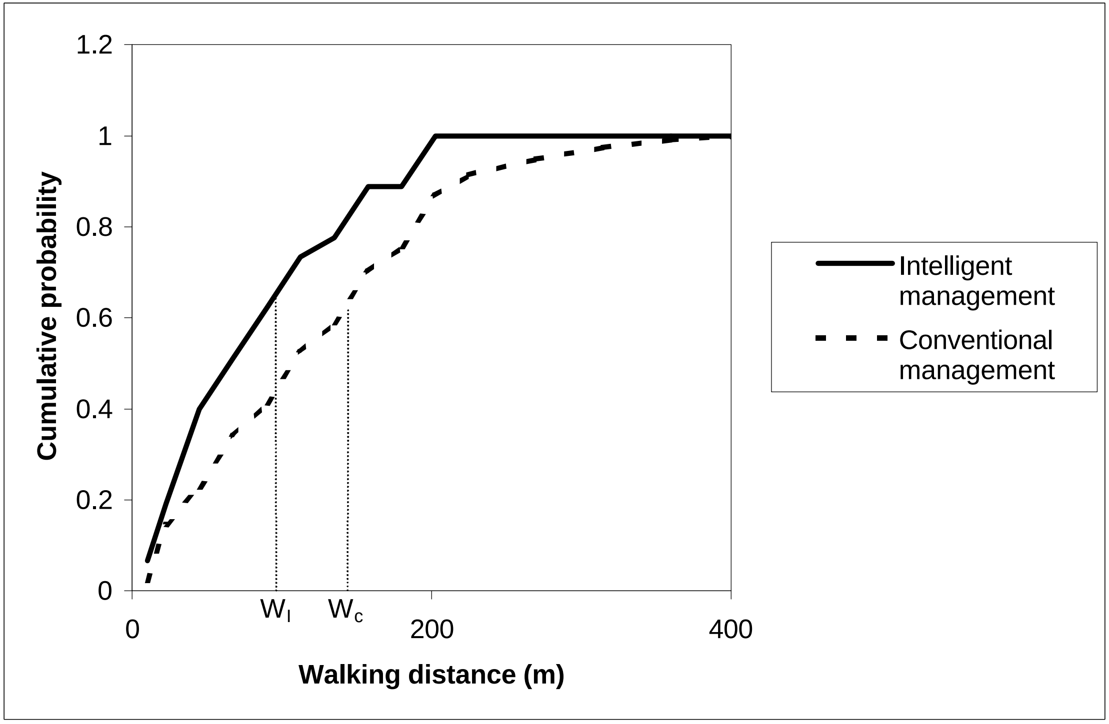

Figure 2: Passenger walking distances with and without intelligent gate assignment for a linear midfield concourse (high transfer rate, 60%)

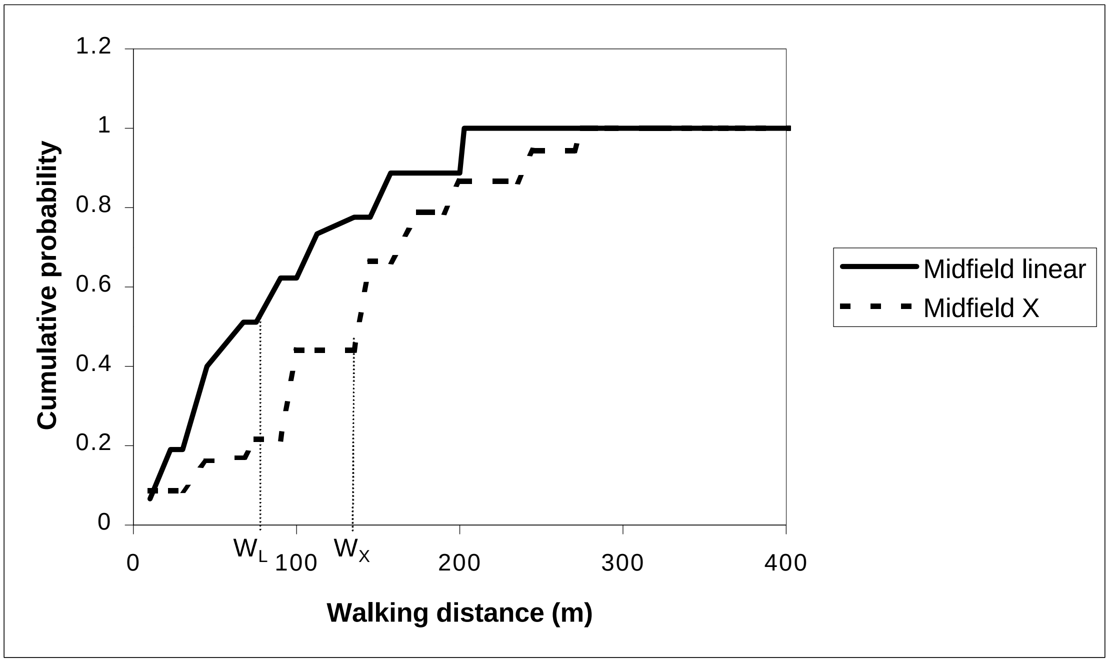

Figure 3: Passenger walking distances for linear and X-shaped midfield concourses, high transfer rate (60%)

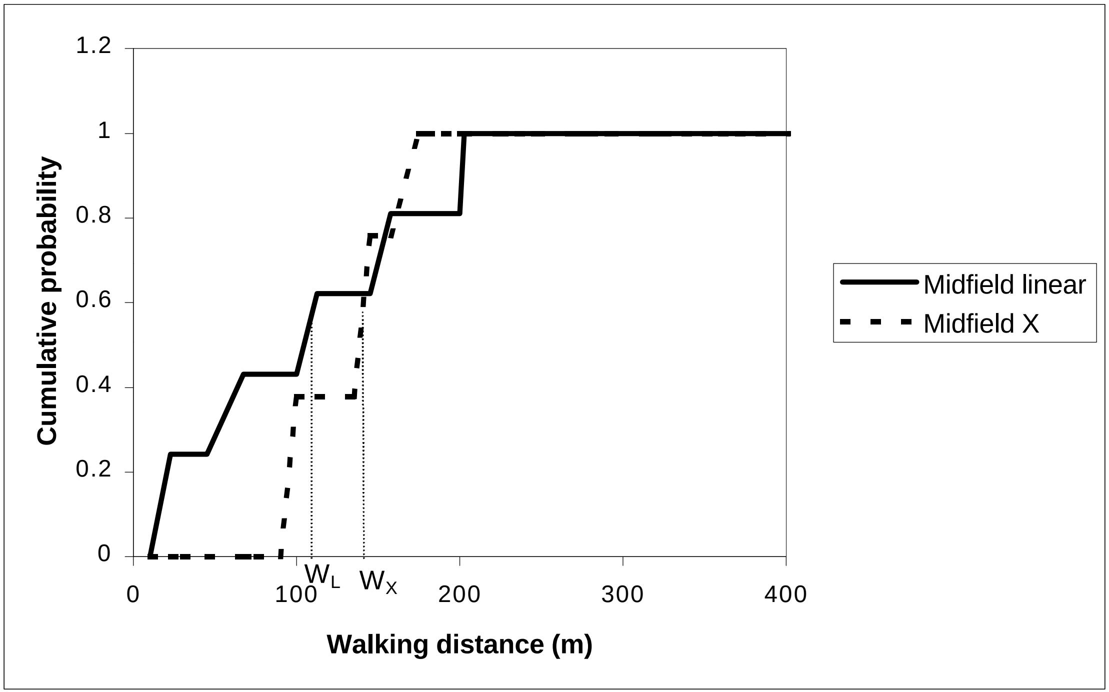

Figure 4: Passenger walking distances for linear and X-shaped midfield concourses, low transfer rate (0%)

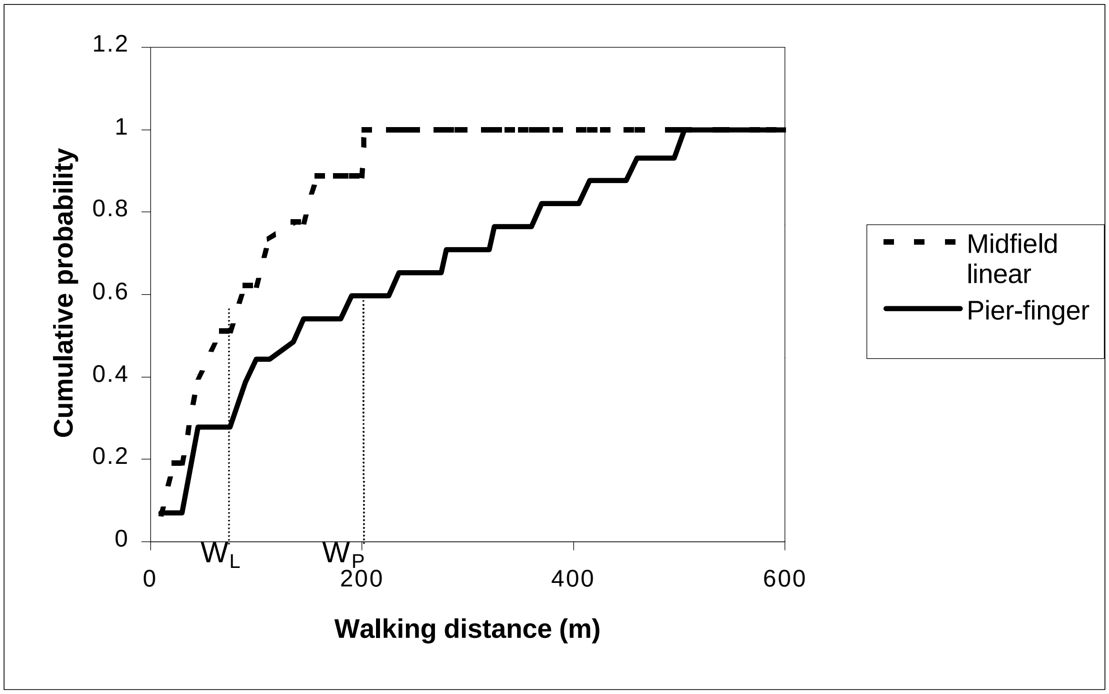

Figure 5: Passenger walking distances for pier finger and linear midfield concourse, high transfer rate (60%)

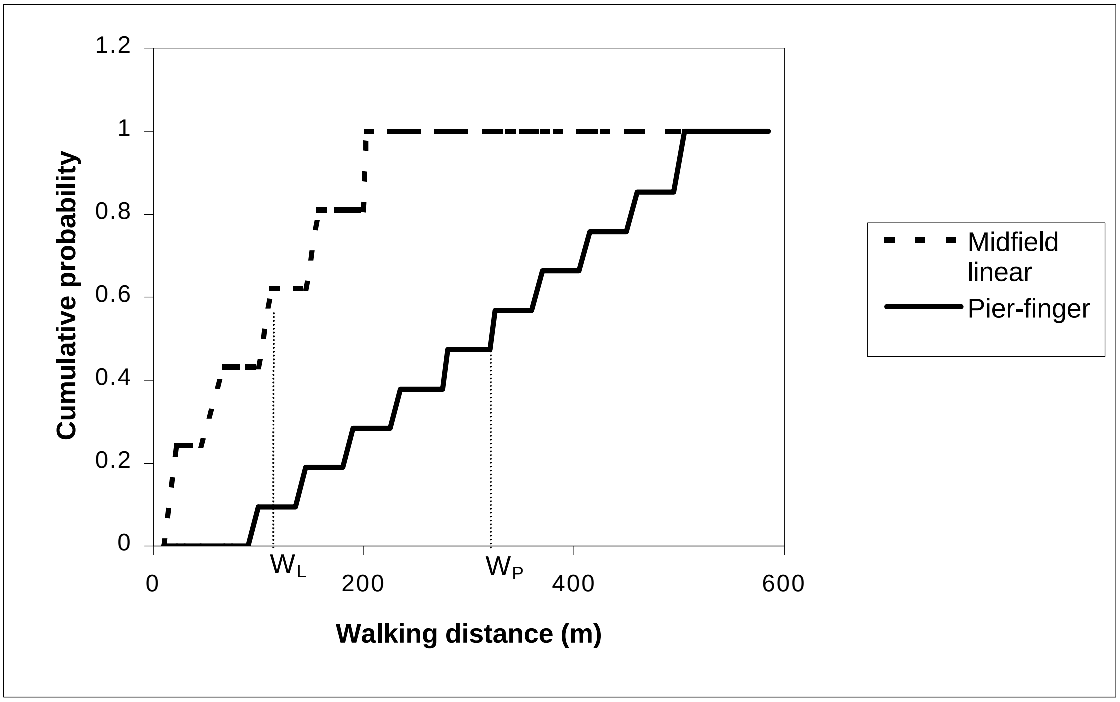

Figure 6: Passenger walking distances for pier finger and linear midfield concourse, low transfer rate (0%)

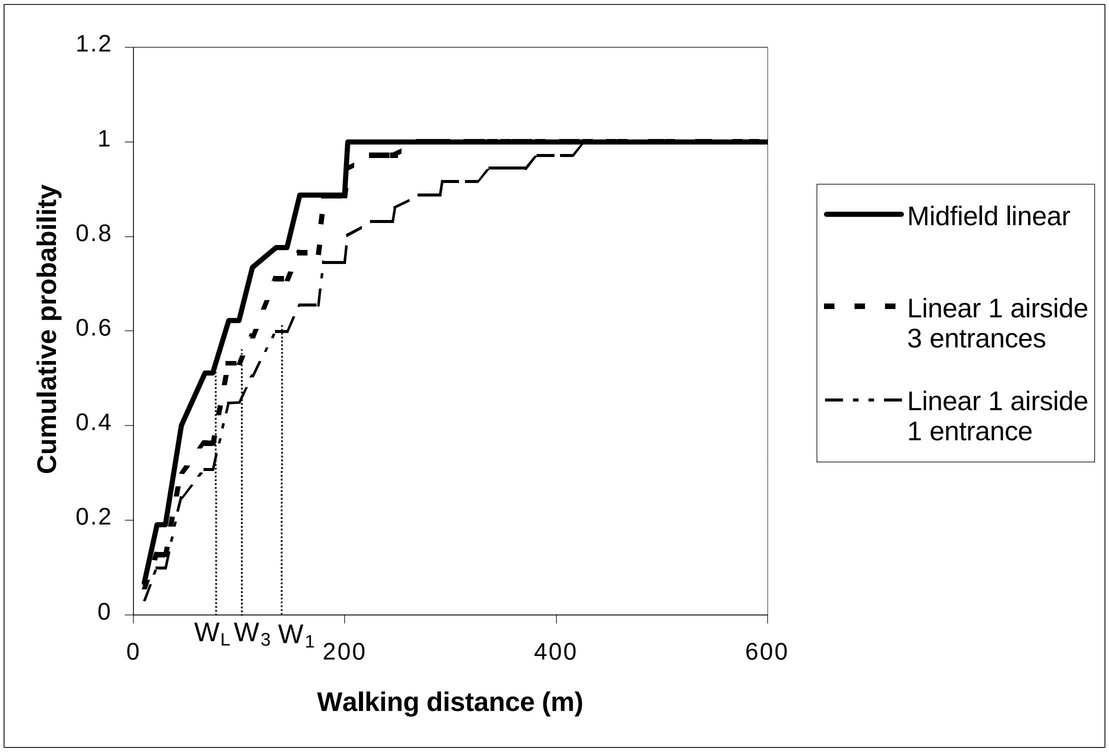

Figure 7: Passenger walking distances for a linear midfield concourse and a linear terminal with one airside, high transfer rate (60%)

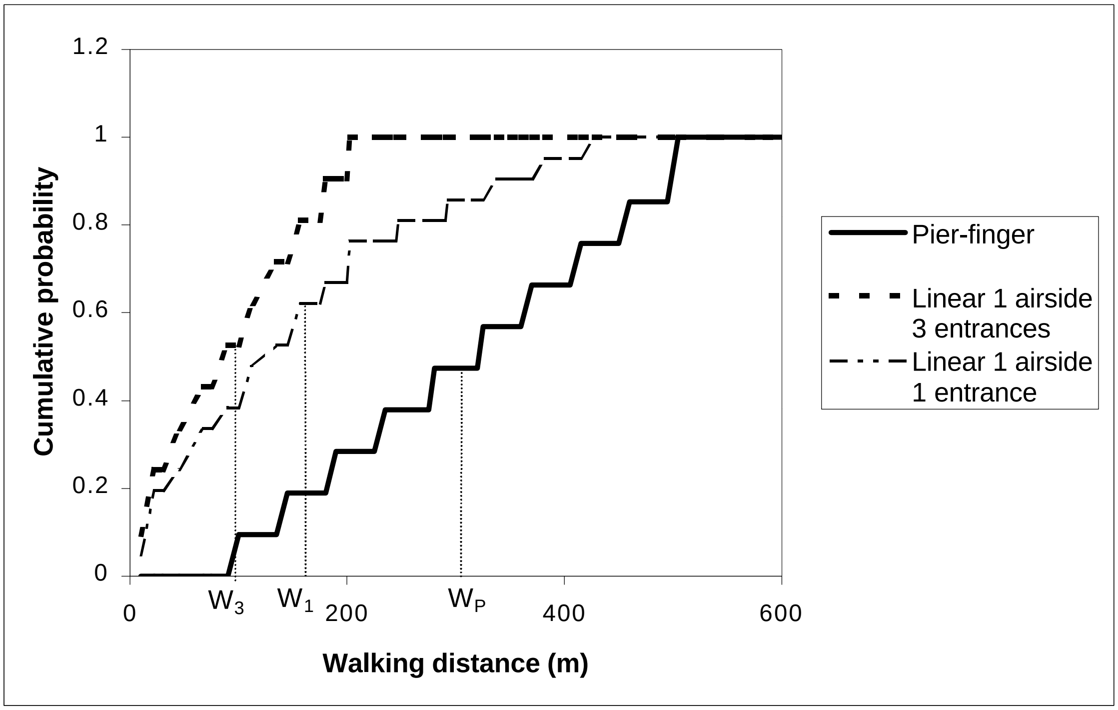

Figure 8: Passenger walking distances for a finger pier and a linear building with one airside, low transfer rate (0%)