Passenger Walking Distance Distribution in Single- and Dual-Concourse Centralized Airport Terminals

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Walking distance within an airport terminal is one important measure of the level of service provided to passengers. The probability distribution of the walking distance of a passenger is used to compare various single- and dual-concourse centralized configurations for a planned airport terminal defined by a given number of identical gates. The walking distance distribution is obtained by using a simulation technique. Terminal configurations are ranked according to the percentage of passengers who must walk less than a specified maximum distance. The effects of installing moving walkways to reduce the effective walking distance are also analyzed. In the numerical example given, a T-shaped configuration is found to be superior to single, basic dual, and rectangular (with moving walkways) configurations.

Walking distance within air terminals is one important measure of the level of service provided to the passengers. Conventional planning methods make reference to the maximum walking distance within an airport *(1)*. However, with simulation techniques, it is possible to investigate the probability distribution of the walking distance of a passenger in a planned airport terminal, which would allow realistic estimates of the level of service in terms of walking distance to be made early in the planning process. Availability of the walking distance distribution would also facilitate selection of terminal configurations that reduce the number of passengers who have to walk excessive distances.

Clearly, passenger walking distance is only one of many factors, such as land constraints, baggage-handling system, taxiing time, landside access, and security requirements, that have to be considered along with capital cost when a terminal configuration is being chosen. However, from the point of view of the level of service provided to passengers, it is one of the most important factors.

Walking distance distribution depends primarily on terminal configuration. This paper deals only with simple configurations in which one or two concourses radiate from a centralized terminal block. However, many small- and medium-sized airports belong to this category. These terminals are called quasi-linear terminals because of their linear geometry and to distinguish them from linear gate arrival terminals. A quasi-linear terminal has a central block that houses the ticketing and baggage-handling areas and aircraft gates that are located on both sides of the concourses. It is a special case of a pier-finger terminal with at most two fingers. The analysis of passenger walks in pier-finger terminals with more than two fingers is more complex and will not be discussed here.

Walking distances can be modified for the benefit of users by the inclusion of moving walkways. The effects of moving walkways on the distribution of passenger walking distance are also investigated.

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CENTRALIZED QUASI-LINEAR TERMINAL CONFIGURATIONS

The model is applicable to the following quasi-linear terminal configurations:

1. Single concourse,
2. Basic dual concourse,
3. T-shaped dual concourse, and
4. Rectangular dual concourse.

Figure 1 is a schematic diagram of a single-concourse terminal. It is assumed that the ticket counters and baggage-handling areas are on separate floors and arranged uniformly in a total distance 2α on both sides of the entrance to the concourse. The arrival and departure gates are assumed to be arranged uniformly on both sides of the concourse. The concourse length is assumed to be β.

Figure 2 is a schematic diagram of the basic dual-concourse terminal configuration. The service counters are arranged uniformly in the distance 2α in the terminal block. The length of each of the two concourses is $\beta/2$. Again, the arrival and departure gates are arranged uniformly along both sides of the concourses.

The T-shaped dual-concourse configuration is a simple modification of the basic dual-concourse configuration in which aircraft arrival and departure gates are not only on both sides of the concourses but also adjacent to the terminal block at the top of the T. Figure 3 is a schematic diagram of such a configuration. The arrival and departure gates are arranged uniformly over a total distance of $4\beta + 2\alpha$. For a given number of gates, the T-shaped configuration requires a shorter concourse than does the basic dual-concourse configuration. Therefore a reduction of passenger walking distances can be realized by selecting a T-shaped configuration.

Figure 4 is a schematic diagram of a rectangular dual-concourse configuration. This configuration can be considered

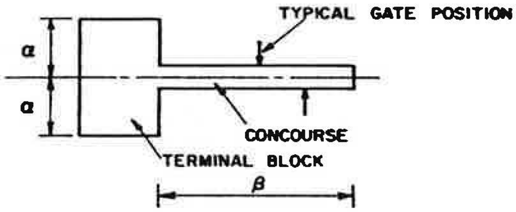

FIGURE 1 Single-concourse centralized terminal.

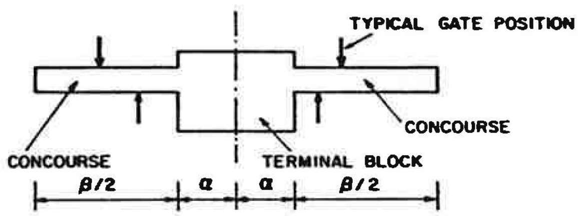

FIGURE 2 Basic dual-concourse centralized terminal.

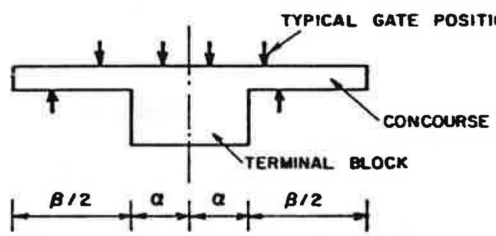

FIGURE 3 T-shaped dual-concourse centralized terminal.

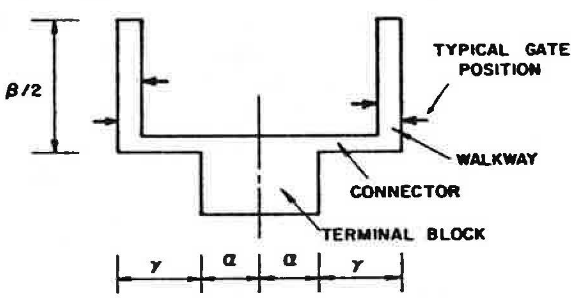

FIGURE 4 Rectangular dual-concourse centralized terminal.

a generalization of the basic dual-concourse configuration with the addition of connectors that provide access to the concourses from the terminal block. From the perspective of walking distance, the basic dual-concourse configuration is equivalent to a rectangular configuration in which connector length α is equal to zero. The angle between a connector and a concourse can range from zero degrees (basic) to 90 degrees (rectangular) depending on the shape of the land area available for the terminal. Walking distances are unchanged if the connector length is kept constant.

Connectors are ideal locations for moving walkways. In practice, some passengers walk on the moving walkway and others stand. Both of these types of passengers, as well as those who avoid the walkway, are considered in obtaining the walking distance distribution of passengers.

SIMULATION MODEL

The simulation proposed here is for use early in the planning stage when various terminal configurations are being considered and compared.

The movement of individual passengers in an air terminal is traced in the model. Passenger movement to retail centers and convenience facilities is not considered. Walking distance between the parking area and the terminal is not considered because it is assumed to be the same for all four configurations. The emphasis here is on measuring the mandatory walking distance within the terminal for the users of the airport.

Passengers are classified as

1. Hub transfers,
2. Normal transfers, and
3. Arrivals and departures.

Hub transfers are preticketed and there is no need for them to walk to a ticketing counter in the terminal block. They walk directly to the departure gates from their arrival gates. However, they have to walk through the central terminal block in a dual-concourse configuration if the arrival gate is in one concourse and the departure gate is in the other concourse.

The normal transfers who transfer from one aircraft to another, but who have to be reticketed at the terminal block, must walk to the terminal block and be served at a ticket counter. Then they walk to the departure gate.

The third category of passengers is arrivals and departures. Arriving passengers walk from the arrival gate to assigned locations in the baggage-handling area. Departing passengers walk from the ticketing counters to the departure gates.

The arrival and departure gates are allocated to all three types of passengers on the basis of an appropriate continuous uniform probability distribution. For passengers who require service at the ticketing or baggage collection areas, service location is allocated according to a continuous uniform probability distribution along an appropriate portion of the terminal block.

At the configuration selection stage of the planning process, it is difficult to estimate the effects of reductions in walking distance that may be achieved later (when the airport is operational) by assigning particular aircraft to particular gates. At this stage, the simulation model cannot account for nonuniformities in the allocation of passengers to gates. The model is useful, however, for obtaining an insight into walking distance distribution according to gate location, ticket counter, and baggage claim selection policies that can be postulated at the initial stages of terminal design.

Further, the long-run distribution for allocating gates to passengers (as schedules, aircraft types, and even airlines change) may be close to uniform if all gates are designed to take most aircraft types because it is not always possible to give priority to large aircraft when assigning close-in gates.

These uniformity assumptions are not valid for analyzing the operation of a functioning terminal (as opposed to a terminal in the planning stages) if airlines consciously select gate positions to minimize walking distances of passengers. For example, adjacent gate positions may be selected for two particular aircraft to reduce the walking distances for a majority of transferring passengers. Preferentially allocating gates closer to the centralized terminal block to relatively larger aircraft would also contradict the assumption of a uniform probability distribution for gate position allocations. Gate assignment policies for functioning airports, which minimize passenger walking distance, have been studied by Babic et al. *(2)* without explicit consideration of transferring passengers.

Initial selection of an appropriate configuration (during the planning stage) and subsequent assignment of aircraft to gates (during the operational stage) are both important for minimizing passenger walking distances.

Measurement of Walking Distance

The walking distance parameters that are generated for a single-concourse configuration are given in Table 1. Two random deviates (β_1 and β_2) are generated for each hub transfer to denote the distance to the arrival gate and to the departure gate, respectively, from the entrance of the particular concourse. For each normal transfer, an additional parameter (α_1) is generated to represent the distance to the entrance of the concourse from the ticketing counter allocated to the passenger. For a nontransfer, only one aircraft gate position is generated (β_1). In this description, $0 < \beta_1 < \beta$, $0 < \beta_2 < \beta$, and $0 < \alpha_1 < \alpha$.

The walking distance parameters that are generated for a basic dual-concourse configuration are given in Table 2. If a transferring passenger has to walk from one concourse to the other, then, irrespective of the relevant ticket counter location, the passenger must walk the full 2α width of the central terminal block in addition to the distances within the concourses. Nonhub transferring passengers who have their arrival and departure gates within the same concourse have to come to the terminal block to process their tickets for the onward trip. It is assumed that these transferring and arriving passengers will find their respective ticket counters in the half of the terminal block closest to their concourses. It is also assumed that the baggage-handling areas will be distributed such that arriving passengers can be served in the half of the terminal block closest to the relevant concourse. The limits on β_1 and β_2 are given by $0 < \beta_1 < \beta/2$ and $0 < \beta_2 < \beta/2$.

Table 3 gives the walking distance parameters of passengers in a T-shaped configuration. The random deviates β_1 and β_2 in the T-shaped configuration are measured from the centerline of the terminal block instead of from the entrance to the concourses as described for previous configurations. The conditional probability density of a passenger walking to a given location along the face of the terminal block is one-half that of the conditional probability density of a passenger walking to a given location in the concourse section, because gates are available on both sides of the concourses and on only one face of the terminal block. Notice that $0 < \beta_1 < \alpha + \beta/2$ and $0 < \beta_2 < \alpha + \beta/2$ for the T-shaped configuration.

Measurement of Walking Distance on Walkways

The additional passenger walking distance parameters due to connectors in rectangular dual-concourse terminals are given in Table 4. If a passenger stands on the moving belt, the distance walked in the connector is assumed to be zero. Though passengers may perceive a finite walking effort even while standing on the walkway, that effort is not quantified here. If the passenger walking speed is V and the walkway speed is V_w, the walking distance for passengers walking on the walkway is given by

$$\gamma_w = \gamma/(1 + V_w/V) \quad (1)$$

Notice that all normal and hub transfers walking from one concourse to the other have to traverse a connector twice. Some of these passengers may walk on both occasions, whereas others may walk only in one direction and ride in the other direction.

It is further assumed that the "walking" passengers walk and the "standing" passengers remain stationary relative to the walkway during the time spent on the walkway.

WALKING DISTANCE DISTRIBUTIONS

The advantage of walking distance distributions is that they allow the planner to determine whether an acceptable level of service, as measured by walking distances, can be provided by a terminal. Walking distance distributions also allow the planner to identify the types of passengers who have to walk excessive distances. When such categories have been identified, it may be possible to devise operational or configurational changes to reduce the walking distances of the affected groups.

The walking distance frequency distribution is obtained for the types of passengers mentioned previously. The simulation model output also shows the percentage cumulative frequency distribution of walking distance for different passenger categories. Further, the model outputs the mean, median, standard deviation, coefficient of variation, and coefficient of skewness of the walking distances for each category of passengers.

All simulations reported here are performed with 33 percent of all passengers considered as transfers. One-half of the transfers are considered hub transfers. A total of 10,000 passengers are simulated for each application.

Single-Concourse Configuration

Figure 5 shows the percentage cumulative frequency distribution of walking distance for a single-concourse terminal in which the half-block width of the terminal (α) is 100 m and the concourse length (β) is 600 m.

The cumulative walking distance distribution can be used to evaluate the proportion of passengers that will have walking distances within an acceptable range. Previous authors have suggested limits in the range of from 250 to 350 m for acceptable unaided walking distance in air terminals *(3, 4)*. If 350 m is assumed to be the limit, then Figure 5 shows that only 50 percent of the total passengers experience walking distances within acceptable limits. The figure also shows that 90 percent of normal transfers and 50 percent of nontransferring passengers walk more than 350 m.

TABLE 1 WALKING DISTANCES IN SINGLE-CONCOURSE CONFIGURATION

Type of Passenger	Arrival Gate	Ticket Counter	Departure Gate	Walking Distance
Hub transfer	β_1		β_2	$\|\beta_1 - \beta_2\|$
Normal transfer	β_1	α_1	β_2	$\beta_1 + \beta_2 + 2\alpha_1$
Nontransfer	β_1	α_1		$\alpha_1 + \beta_2$

TABLE 2 WALKING DISTANCES IN BASIC DUAL-CONCOURSE CONFIGURATION

Type of Passenger	Concourse	Arrival Gate	Ticket Counter	Departure Gate	Walking Distance
Hub transfer	Same	β_1		β_2	$\|\beta_1 - \beta_2\|$
	Both	β_1		β_2	$\beta_1 + \beta_2 + 2\alpha$
Normal transfer	Same	β_1	α_1	β_2	$\beta_1 + \beta_2 + 2\alpha_1$
	Both	β_1	α_1	β_2	$\beta_1 + \beta_2 + 2\alpha$
Nontransfer		β_1	α_1		$\beta_1 + \alpha_1$

TABLE 3 WALKING DISTANCES IN T-SHAPED CONFIGURATION

Type of Passenger	Concourse	Arrival Gate	Ticket Counter	Departure Gate	Walking Distance
Hub transfer	Same	β_1		β_2	$\|\beta_1 - \beta_2\|$
	Both	β_1		β_2	$\beta_1 + \beta_2$
Normal transfer	Same	β_1	α_1	β_2	$\|\beta_1 - \alpha_1\| + \|\beta_2 - \alpha_1\|$
	Both	β_1	α_1	β_2	$\|\beta_1 - \alpha_1\| + \alpha_1 + \beta_2$
Nontransfer		β_1	α_1		$\|\beta_1 - \alpha_1\|$

TABLE 4 ADDITIONAL WALKING DISTANCE IN RECTANGULAR DUAL-CONCOURSE CONFIGURATION

Type of Passenger	Concourse	Walking on Walkway	Standing on Walkway
Hub transfer	Same	0	0
	Both	$2\gamma_w$ or γ_w	0
Normal transfer		$2\gamma_w$ or γ_w	0
Nontransfer		γ_w	0

Table 5 gives the mean and standard deviation parameters for the four quasi-linear configurations. Vandebona and Wirasinghe *(5)* have described an analytical model suitable for the computation of mean and standard deviation of walking distances in centralized quasi-linear terminals and cross verified the analytical results with the means and standard deviations available from the simulation model.

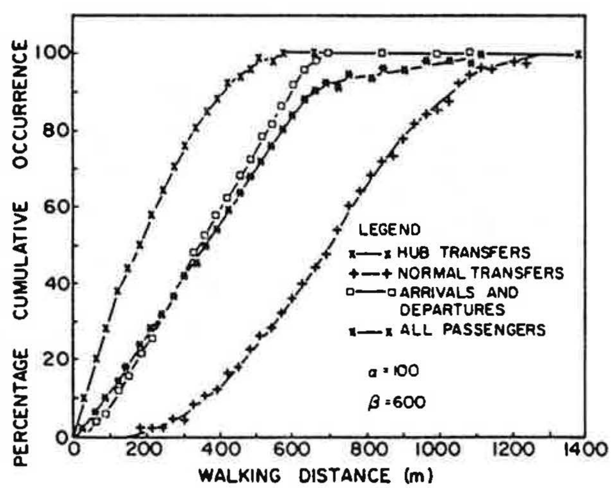

FIGURE 5 Walking distance distribution for single-concourse configuration.

Basic Dual-Concourse Configuration

Figure 6 shows the percentage cumulative walking distance distribution in a basic dual-concourse configuration. For the purpose of comparing walking distances, the numerical values selected for α and β are unchanged form those for a single-concourse configuration. Therefore the half-block width of the new centralized terminal block is 100 m. Each concourse is 300 m long.

According to Figure 6 and Table 5, the basic dual-concourse configuration reduces the walking distances of most categories of passengers. The types of passengers who experience long walking distances are the hub and normal transfers who walk from an arrival gate in one concourse to a departure gate in the other concourse.

Almost 80 percent of all passengers in the dual-concourse terminal experience walking distances within the acceptable limit of 350 m. However, almost 90 percent of passengers transferring from one concourse to the other walk distances greater than the acceptable limit because they have to cross the full width of the terminal block.

TABLE 5 WALKING DISTANCE PARAMETERS BY SIMULATION

Type of Passenger	Percentage Simulated: Single Concourse	Percentage Simulated: Dual Concourse	Single Concourse (α = 100, β = 600)	Basic Dual Concourse (α = 100, β = 600)	T-Shaped Dual Concourse (α = 100, β = 500)	Rectangular Dual Concourse (α = 100, β = 600, γ = 50): Without Walkway	Rectangular Dual Concourse (α = 100, β = 600, γ = 50): With Walkway[a]
1. Hub transfers (same concourse)	16.5	8.25	198 (141)	99 (73)	106 (78)	103 (72)	103 (72)
2. Normal transfers (same concourse)	16.5	8.25	695 (250)	399 (135)	302 (130)	499 (140)	437 (141)
3. All same-concourse transfers (Categories 1 + 2)		16.5		249 (185)	204 (145)	301 (227)	270 (222)
4. All other-concourse transfers		16.5		498 (122)	390 (132)	602 (117)	540 (118)
5. All transfers (Categories 3 + 4)	33	33	446 (321)	373 (200)	297 (167)	451 (235)	405 (213)
6. Arrivals and departures	67	67	349 (174)	199 (91)	151 (88)	249 (91)	279 (92)
7. All passengers	100	100	381 (238)	257 (160)	199 (138)	316 (181)	279 (168)

NOTE: Standard deviation is shown within parentheses.
[a]Walkway speed is assumed to be one-half of mean walking speed.

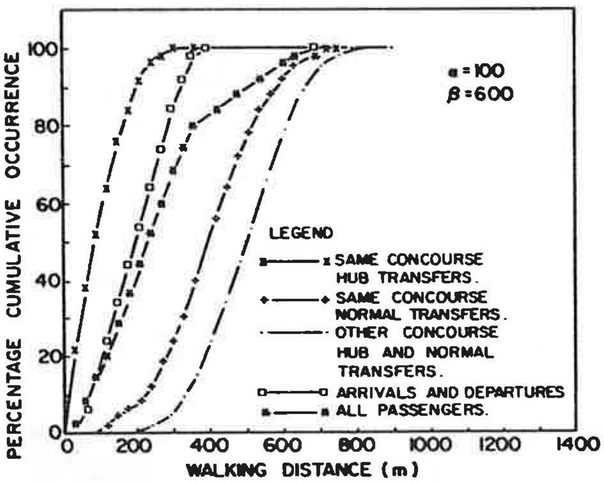

FIGURE 6 Walking distance distribution for basic dual-concourse configuration.

T-Shaped Dual-Concourse Configuration

In the T-shaped dual-concourse configuration, the β-value is reduced to 500 m because gates are also available along one face of the block that is 100 m long. Figure 7 shows that even further improvements in walking distance distribution can be obtained by adopting this configuration. About 90 percent of the passengers have walking distances within the acceptable limits. These improvements are due to the reduction in concourse length and the availability of some gates that can be directly accessed from the terminal block.

EFFECT OF WALKWAYS ON WALKING DISTANCE

Consider the rectangular configuration shown in Figure 4. A T-shaped or basic dual configuration will always give shorter walking distances than a rectangular configuration. Consequently, rectangular configurations should be adopted only if required by other considerations. The α- and β-values are assumed to be the same as those for other non-T-shaped configurations. To minimize walking distance, an attempt should be made to minimize the length of the connectors leading to concourses. However, adequate separation should also be provided between parallel concourses to allow for taxi lanes and sufficient clearance for parked aircraft. According to U.S. Department of Transportation *(3)* requirements, the rectangular configuration would require connectors at least 50 m long (i.e., γ = 50) for nose-in aircraft parking.

Figure 8 shows that only 65 percent of passengers walk acceptable distances in the configuration if the connectors are not equipped with moving walkways.

It was mentioned previously that the simulation model can be used to evaluate the effect of walkways. Passengers are

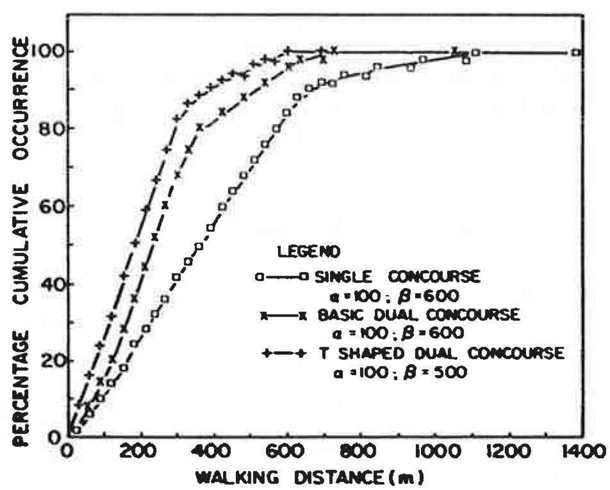

FIGURE 7 Comparison of walking distance distributions.

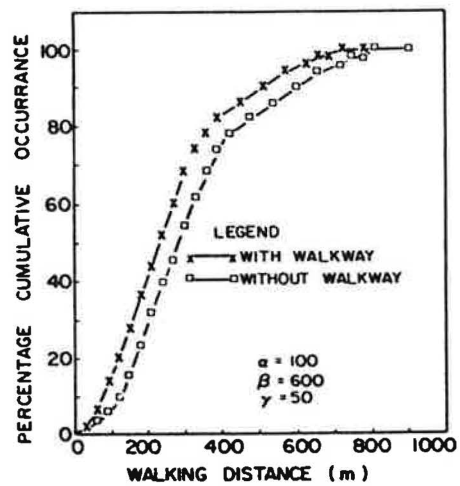

FIGURE 8 Walking distance distribution for rectangular configuration.

classified in three categories according to their behavior when they negotiate a connector: avoiders, walkers, and standees. Walkway avoiders are passengers who would use the alternative walking path beside the walkway. Horonjeff and Hoch *(1)* demonstrate that the percentage of people bypassing the walkway at an airport ranges from 9 to 20 percent, depending on the volume of passenger traffic, and that about 70 percent of the users of the walkway will be standees when passenger headway is less than 10 sec. On the other hand, the relative number of walkers increases when the walkway is less congested. For example, all users walked on the walkway when passenger headway was greater than 20 sec. It is assumed in the application described here that there are equal numbers of standees and walkers and that there are 10 percent avoiders.

Generally, mean passenger speed (V) is 85 m/min. Operating speeds of low-speed walkways are in the range of 35 to 55 m/min *(1, 6)*. The speed of the walkway in proportion to the mean walking speed is assumed to be 0.5 for the simulation.

The simulation is conducted with the walkways installed in the full length of the connectors of the rectangular configuration. The data in Table 5 indicate that, except for hub transfers who walk within a single concourse, all passenger categories benefit from the introduction of walkways. Figure 8 shows walking distance distributions before and after the introduction of walkway. Walkways increased the acceptability of the walking distance for up to 75 percent of passengers from the previous 65 percent level.

CONCLUSIONS

The simulation technique can be used to estimate the passenger walking distance distribution of a particular terminal configuration. The distribution can be used to compare various terminal configurations and to estimate improvement in level of service in terms of walking distance of passengers when moving walkways are introduced.

The simulation program that is currently available can be used to study any quasi-linear terminal configuration during the initial planning stages. Simulations of other (nonlinear) configurations are being developed *(7)*.

A comparison of the fraction of passengers who walk distances not more than the acceptable maximum of 350 m, for the various quasi-linear configurations, is given in Table 6. The T-shaped configuration provides the best level of service from this point of view. Further investigations (not reported in this paper) show that the T-shaped configuration is suitable for most fractions of transfers. A single-concourse terminal can, however, minimize walking if (almost) all passengers are hub transfers.

TABLE 6 COMPARISON OF QUASI-LINEAR CONFIGURATIONS

Configuration	Percentage of Passengers Walking Less Than 350 m
Single concourse	50
Dual concourse	80
T-shaped	90
Rectangular	65
Rectangular with walkway	75

An advantage of the simulation technique is the obtainability of walking distance distributions in addition to the walking distance statistical parameters. Walking distance distributions provide a better means of comparing different options than do parameters such as maximum walking distance.

One objective of the planner in selecting a terminal configuration could be to maximize the percentage of passengers that would walk less than the acceptable limit for walking distance. Walking distance distributions facilitate the comparisons required for this purpose.

ACKNOWLEDGMENTS

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REFERENCES

1. R. Horonjeff and C. J. Hoch. Some Facts About Horizontal Moving Sidewalks at Airports. *Proc., Transportation Facilities Workshop*, ASCE, New York, 1974, pp. 323–334.
2. O. Babic, D. Teodorovic, and V. Tosic. Aircraft Stand Assignment to Minimize Walking. *Journal of Transportation Engineering*, ASCE, Vol. 110, No. 1, Jan. 1984, pp. 55–66.
3. *The Apron-Terminal Complex: Analysis of Concepts for Evaluation of Terminal Buildings*. U.S. Department of Transportation, 1973.
4. W. Hart. *The Airport Passenger Terminal*. John Wiley and Sons, Inc., New York, 1985, 248 pp.
5. U. Vandebona and S. C. Wirasinghe. *Airport Terminal Walking Distance Parameters for Centralized Single and Dual Concourse Configurations*. Research Report CE86-4. Department of Civil Engineering, The University of Calgary, Calgary, Alberta, Canada, 1986, 35 pp.
6. Jamieson, MacKay and partners and Renton Howard Wood Levin partnership. *Speedway Cost/Benefit Study*. SR 273. Transportation and Road Research Laboratory, Crowthorne, Berkshire, England, 1977, 57 pp.
7. S. C. Wirasinghe, S. Bandara, and U. Vandebona. Airport Terminal Geometries for Minimal Walking Distances. Presented at Tenth International Symposium on Transportation and Traffic Theory, Boston, Mass., 1987.

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