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Optimal Configuration of Airport Passengers Terminals

This work presents an evaluation of walking distances and construction costs for airport passenger terminals as a function of the four configuration concepts mentioned in airport theory literature (pier, satellite, linear, and transporter), and as a function of various demand levels. The linear concept presented the shortest walking distance; the transporter concept presented the lowest construction costs. The results provided are useful for airport planners to assist them in the economic and operational assessment of building alternatives for new airport passenger terminals.

By Anderson Ribeiro Correia and Cláudio Jorge Pinto Alves

There are several useful configuration types that can be used to design an airport passenger terminal. When you look at all the configurations available in books, each of them presents advantages and disadvantages. However, none of them can be seen as an optimal concept. On the other hand, there are certain advantages that some concepts provide based on the circulation of passengers.

Designers face a crucial task when they select the configuration of airport passenger terminals. The decisions they make about the shape of the buildings, the layout of the airport, and its location, have major consequences on the performance and profitability of the airport as an organization (de Neufville and Odoni, 2002). Horonjeff and McKelvey (1994) present a list of the main parameters that can be influenced by the airport design. These are:
Processing cost per passenger;
Walking distance for various types of passengers;
Passenger delays in processing;
Occupancy levels and degree of congestion;
Aircraft maneuvering delays and costs;
Aircraft fuel consumption in maneuvering on the airport between runways and terminals;
Construction costs;
Administrative, operating, and maintenance costs;
Potential revenue sources and the expected level of revenues from each source.

The above-mentioned parameters are representative of the different perspectives by which an airport can be looked at. These parameters are functions of units such as passengers, airlines, airport administration, governmental offices, etc. In this case, the problem at hand is the multitude of attributes, which demands complex and efficient procedures to select suitable configurations.

The purpose of this paper is to quantitatively evaluate the characteristics of the airport passenger terminal configurations that are available in airport theory literature. First, the paper starts with a review of airport literature. Seco nd, the most important performance parameters will be selected, based on an importance hierarchy. Third, a methodology will be suggested to evaluate the configurations, based on the selected parameters. Finally, the recommended configurations will be presented, according to the assumptions provided in this paper.

Literature Review

The first attempts to evaluate airport passenger terminal configurations were very descriptive by nature (de Neufville, 1976; Hart, 1985). The configuration characteristics were presented as a function of the author's experience on airport design and management, which lacked an analytical approach. De Neufville (1976) did not intend to recommend any configuration type, stating that, for each particular case, the pattern of variations in the traffic, the intensity of transfer between flights, and the volume of crypto-transfers for picking up cars and similar purposes, should be defined separately. Hart (1985) provided definitions of four terminal concepts:

Satellite Concept: in the satellite concept, aircraft are parked in a cluster, which surrounds a structure that is connected to the main terminal by a corridor or concourse positioned below, on, or above grade.

Pier Concept: in the pier concept, aircraft are parked in a line at either side of a connecting corridor or concourse attached to the main terminal. In both the satellite and pier concepts, passenger ticketing and inbound and outbound baggage handling functions are centralized, mostly in the main terminal.

Linear Concept: in the linear concept, aircraft are parked in a single line at a corridor or concourse connecting with other functional elements of the terminal.

Transporter Concept: the transporter concept involves a return to earlier modes of operation where passengers were transported between aircraft and the terminal in buses or other vehicles.

Figure 1 provides the illustration of these four concepts.

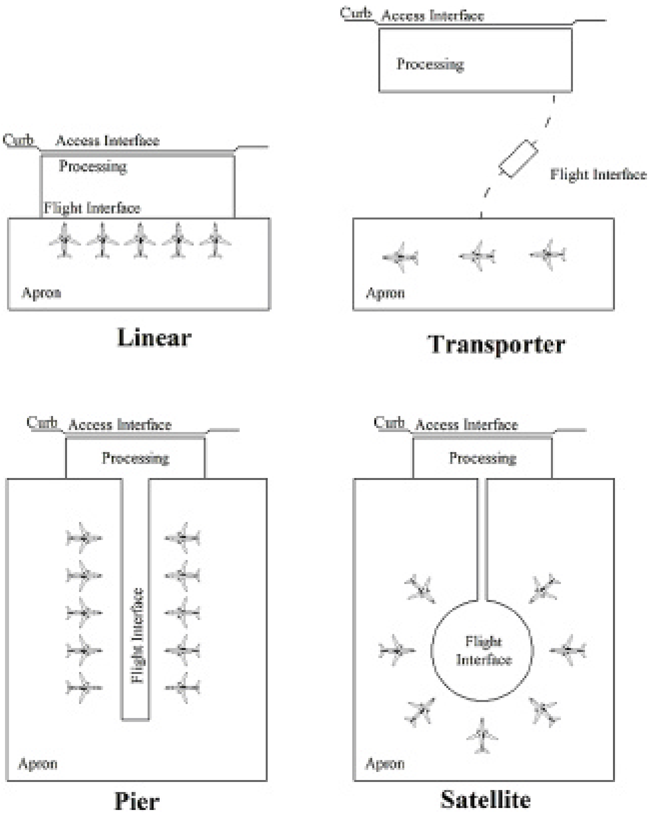

Figure 1: Concepts for Passenger Terminals (Horonjeff and McKelvey, 1994).

Based on these definitions, the author provided the applicability of these four concepts as a function of traffic types and volumes, taking into consideration operational and cost parameters (Table 1).

Table 1: Concept Application by Range of Annual Enplanements

Airport Size by Emplaned Pax/Year	Concepts Applicable			
	Linear	Pier	Satellite	Transporter
Feeder under 25,000	y			
Secondary 25,000 to 75,000	y			
75,000 to 200,000	y			
200,000 to 500,000	y	y		
Primary over 75% PAX originations 500,000 to 1,000,000	y	y	y	
Over 25% PAX transfers 500,000 to 1,000,000	y	y	y	
Over 75% PAX originations 1,000,000 to 3,000,000		y	y	y
Over 25% PAX transfers 1,000,000 to 3,000,000		y	y	
Over 75% PAX originations over 3,000,000		y	y	y
Over 25% PAX transfers over 3,000,000		y	y	

Source: Hart (1985)

Subsequent work has been very analytical, such as identifying the characteristics of configurations under different design and operational assumptions. Wirasinghe et. al. (1987) suggested a method to determine the optimum geometries for equi-length pier-finger type terminals that minimized the passenger walking distances within the terminal and that identified the fraction of transferring passengers at the number of gates as the influencing factors in selecting the terminal geometry. Bandara and Wirasinghe (1992) presented the walking distance calculation for pier, pier-satellite and satellite configurations. The size of the terminal is analytically determined as a function of the number of gates. For a wide range of passenger type mixes and number of gates, a semi-centralized pier configuration appears to be the best terminal configuration with respect to passenger walking. Wirasinghe and Bandara (1992) presented a method to determine the optimal geometry for a pier configuration of a terminal with the use of people-movers. Under certain circumstances, it is possible to limit the number of remote piers and the length of the piers in order to satisfy space and airline requirements. In the case studies of Denver and Atlanta Hartsfield, it was concluded that the optimal geometry is proportional to the walking distance cost per unit of time and transportation costs per unit of time. Robuste and Daganzo (1991) and Robuste (1991) analyzed and compared several centralized airport configurations in terms of the mean walking distance and baggage handling, with all transfer passengers being considered as hub transfers. Since they concentrated on hub airports only, their conclusions may be useful to hub airports or only to those with very high percentages of hub-transferring passengers. The overall conclusion of the latter was that finger-pier configurations were preferable with regard to minimizing walking distances.

De Neufville et. Al (2002) used excel spreadsheet models to analyze several configuration types as a function of walking distances and the amount of transfer passengers. They also intended to analyze the effect of intelligent gate management on the average walking distances. The reported results were for a hypothetical 20-gate passenger building that served large commercial aircrafts. Table 2 shows the results of the study.

Table 2: Performance of Airport Passenger Configurations

Configuration	Average walking distance (m/person)	
	Transfer Rate High (60%)	Transfer Rate Low (0%)
Mid-field concourse Linear		
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

Source: de Neufville et. al (2002)

In short, the analysis reveals the advantages of intelligently managed linear midfield concourses and the disadvantages of finger piers, with regard to walking distances when airport operators manages gates intelligently. Considering the size of terminals, the paper was not able to provide the variation of walking distances as a function of number of gates. The research was conducted for a hypothetical terminal with a fixed number of 20 gates that serve large commercial aircraft.

De Barros and Wirasinghe (2003) analyzed passenger terminal configurations for accommodating new large aircrafts (NLA) operations. The analysis was done individually for a single pier, several types of pier-satellites, and a set of remote parallel piers connected by an automated people-mover. The overall disutility of walking and riding an APM was taken for the criterion for optimality. The objective of the paper was to find the best locations for NLA gate positions.

Most of the previously presented studies are characterized by their analysis of large commercial airports (e.g. large number of gates, large aircrafts, pier and satellite terminals, hub terminals, etc). However, in real life, most airports located in countries outside the North-American/Europe axis are somewhat different than that perspective. For instance, there are large airports in Brazil (e.g. São Paulo/Guarulhos, Brasília, Rio de Janeiro/Galeão), but the average airport network is composed of small and medium airports. One of the studies mentioned in the literature used Atlanta Hartsfield International Airport as a study case. This airport processed more than 80 million passengers in 2000. This amount of traffic is more than 6 times the volume of passengers handled at the biggest airport in South America. Taking this into account, it is necessary to develop an analysis of configurations that are suitable to the local needs.

Parameters

Traditionally, the walking distance parameter has been used to analyze configurations of airport passenger terminals in the user perspective. Airline passengers typically have to walk great distances under trying conditions. They often have to traverse hundreds of meters, are burdened with bags, are unable to move quickly – because they are very young or infirm and trying to find their way in a confusing environment, or are stressed by the pressure of meeting a departure time. Thus, minimization of walking distances is an important criterion for the design of airport passenger buildings (de Neufville et. al, 2002). Caves and Pickard (2000) developed research on the satisfaction of human needs in airport passenger terminals. According to them, it is common to comply with the passengers' needs for short and predictable times to move through the terminal by keeping in check the distance from the drop-off curbside to the gate serving the furthest aircraft. Concerning the use of moving walkways and people-mover systems, they mention that passengers who have to use them, lack faith in the ability that those devices deliver them on time, and thus consider those to be an extra inconvenience. Seneviratne and Martel (1991) held a passenger survey at Canadian airports and found that walking distance and information are the most important factors that influence the quality of service of the circulation section at airport passenger terminals. Because on these findings, walking distance is one of the factors in the analysis that will be developed in this paper.

Even though every airport should be encouraged to offer a reasonable level of service for its passengers, there are some constraints that affect every design project that include cost considerations. De Neufville and Odoni (2002) mentioned the most important future trends of air transportation, which are long-term growth, commercialization, globalization, and technical changes (e.g. electronic commerce, NLA). The implications of these trends for airport systems planning and design result in a change of context, objectives and criteria of excellence. The context is commercial; the objectives focus more on performance than on monuments; the criteria of excellence will focus on cost-effectiveness, value for money, efficiency and profitability. Taking into account all these implications, construction costs are one of the most important factors to include in the analysis of terminal configurations. For this reason, construction costs will be an evaluation factor for the proposed terminal configurations.

The Suggested Methodology

The analysis will be done with three annual demand levels (500,000, 2,000,000, and 5,000,000 passengers). These levels have been identified as representative of the majority of airports located in South America. For instance, in Brazil, there are only a few airports with annual volumes higher than 5,000,000 pax/year. On the other hand, most airports with volumes lower than 500,000 pax/year were designed using the linear concept; in those cases, a study of different configurations is not necessary.

Figure 2: Methodology Flowchart

The main hypothesis is, that for each of the proposed demand levels, there may exist a more suitable configuration as a function of the analysis criteria suggested in this paper. In addition, the configuration that provides more advantages will be identified for each criterion. Figure 2 provides the methodology flow-chart. The configuration types pier, transporter, linear and satellite will be designed and evaluated as a function of the demand levels and proposed criteria.

Some hypotheses concerning the sizing and location of components, aircraft positioning through the gates, walking distance calculation, and construction costs assessments have been adopted. They were thoroughly presented at Correia (2000) and include the following:

Assumed passenger flow for walking distance calculations: curbside/parking – check-in counter – departure lounge - boarding gate – aircraft – baggage claim – curbside/parking. Walking to concessions has not been considered, because that is not a compulsory service.
It is assumed that the airport has enough space for implementing the proposal alternatives.
Terminals are designed in a single building with two levels. Ground floor: arriving passengers; upper floor: departing passengers. This practice is standard in the majority of airports within the annual demand range used in this work.
Concession areas distribution: 80% - departing floor / 20% arriving floor (Garcia, 1995).
Peak-hour formula used to transform annual volumes into hour volumes provided by the DAC (Brazilian Department of Civil Aviation).
Amount of passengers using parking – 60% (Infraero data).
Amount of connections: 10% (obtained by observation of selected airports).
Walking costs: US$ 3.47/km (Wirasinghe, 1992).
Construction costs: US$ 641/m^2 (Wirasinghe, 1992).
Mix of aircraft: different for each demand level studied. It was obtained by observation of selected airports.
Administrative and support areas have been sized using Infraero data.

Results

Application of the methodology provides walking distances distributed by annual volumes, concept types, and movement types (Table 3).
According to Table 3, walking distances increase as a function of annual volumes. For instance, a Linear terminal is associated with average walking distances of 85m (500.000pax/year), 109m (2.000.000 pax/year), and 128m (5.000.000 pax/year). It can be seen that the increasing rate is not linear. Table 3 also suggests that walking distances vary as a function of the terminal type selected. In some cases, the differences are considerable. Annual walking costs have been calculated by applying walking costs parameters defined in the previous section.

Tables 4 and 5 provide the terminal areas and construction costs associated with the annual volumes and proposed concept types.

Table 4: Terminal Areas (m^2)

Concept	Terminal Areas (m^2) 500.000 pax	2.000.000 pax	5.000.000 pax
Linear	4,943	13,471	24,833
Transporter	3,755	10,206	20,705
Pier	5,141	13,228	26,024
Satellite	5,036	12,379	24,,070

Table 5: Annual Construction Costs (US$)

Concept	Annual Construction Costs US$ 500.000 pax	2.000.000 pax	5.000.000 pax
Linear	32,227	87,836	161,913
Transporter	24,482	66,541	134,999
Pier	33,518	86,247	169,674
Satellite	32,832	80,714	156,933

Construction costs have been amortized over a period of 25 years with an interest rate of 10% per annum.

Terminal areas of selected Brazilian airports have been presented in Table 6 in order to provide a comparison basis to check the areas of hypothetical terminals developed through the use of the proposed methodology (Table 4). It can be observed that the methodology application provides results that are similar to the areas of existing terminals.

Table 3: Average Walking Distances (m) and Walking Costs (US$)

Annual Volume	Concept	Walking Distance (m) Departing	Arriving	Transfer	Average	Annual Walking Cost (US$)
500.000 passengers	Linear	95	60	155	85	147,817
	Pier	156	154	226	162	280,796
	Transporter	96	94	107	96	166,477
	Satellite	214	216	344	226	392,634
2.000.000 passengers	Linear	117	70	245	109	754,593
	Pier	245	251	357	259	1,796,877
	Transporter	140	146	147	143	994,544
	Satellite	270	277	408	287	1,991,544
5.000.000 passengers	Linear	136	78	318	128	2,224,374
	Pier	310	336	444	335	5,813,170
	Transporter	160	186	144	170	2,954,237
	Satellite	302	328	428	327	5,666,215

Table 6: Terminal Areas of Selected Brazilian Airports (1999)

Airport	City - State	Annual Passenger Volume	Terminal Area (m^2)
VIX –Vitória	Vitória - ES	620,000	3,293
GYN – Goiânia	Goiânia - GO	650,000	4,847
FOR – Pinto Martins	Fortaleza - CE	1,450,000	10,619
POA – Salgado Filho	Porto Alegre - RS	2,000,000	14,055
SÃO – São Paulo / Congonhas	São Paulo - SP	6,600,000	37,301

Finally, in order to facilitate the comparison between the various terminal concepts and several demand levels, table 7 presents the more recommended and less recommended configuration types as a function of annual passenger volumes, walking distances and construction costs.

Table 7: Recommended Configurations

ANNUAL PASSENGER VOLUMES		500,000	2,000,000	5,000,000
MORE RECOMMENDED	WALKING DISTANCE	LINEAR	LINEAR	LINEAR
	CONSTRUCTION COSTS	TRANSP.	TRANSP.	TRANSP.
LESS RECOMMENDED	WALKING DISTANCE	SATEL-LITE	SATEL-LITE	PIER
	CONSTRUCTION COSTS	PIER	PIER	PIER

It is important to notice that additional parameters could be adopted to select a given terminal concept. The following section suggests some of these parameters, which have not been the subject of this study because of research cost and time constraints.

Conclusions

This paper has provided a methodology to analyze the level of service provided by several configuration types as a function of annual volumes and selected criteria. Analysis of existing airport terminals is not very useful, because each airport has been designed under different LOS standards, traffic characteristics, and cost constraints. In this case, the provision of a method to develop hypothetical terminals presents a more suitable way to analyze configuration types objectively and analytically.

An important conclusion of this work is that linear and transporter configurations are more suitable than satellite and pier configurations, considering the employed criteria, the selected annual passenger volumes (500,000 – 5,000,000), and the methodology assumptions provided. De Neufville et. al (2002) too, have found that linear configurations are preferred over pier fingers with regard to the walking distance criterion and for a 20-gate terminal serving large commercial aircrafts (Table 2). Nevertheless, they have not provided walking distances for different demand levels, as it has been presented in this work.

The construction costs provided in this work are a unique contribution of this research, indicating that some terminal configurations provide space economies by sharing space (concessions, lounges etc) and by centralizing operations. In this particular case, with regard to the cost criterion, the transporter concept is recommended to be used, especially for airports that have severe space constraints.

Future research is necessary to check the variation of walking distances as a function of transfer traffic amount. In this work, it has been set at 10%. However, this value is considerably higher for hub airports. Additionally, more criteria (e.g. aircraft taxiing costs, total area of airports, and commercial revenues) could be included to provide a more comprehensive analysis of configuration types for airport passenger terminals.

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