### **ROBUST CONCEPTION OF AIRPORT-TERMINAL LAYOUTS**

Evaluation methodology based on future scenarios Maria Carolina Gil Ribeiro

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### ABSTRACT

Air transport industry has suffered a variety of changes over time due to external and internal factors. Because these factors behave in a way that is not always possible to predict, the planning and design of an airport terminal faces many uncertainties. Therefore, it is urgent to identify a methodology to evaluate what layout concepts for a terminal best adapt to uncertain future changes. To determine the robustness of the building, it is essential to identify the factors of change and their noise variables and to analyse air transport industries and various airport terminals.

Through analysis of the past, present and future behaviour of air transport, it is possible to identify the factors of change and the noise variables that will lead to the definition of different future scenarios. The creation-process scenarios are the base to identify requirements and point of views for the evaluation of airport-terminal layout concepts.

### 1. INTRODUCTION

In the last few years, air transport industry has seen changes with repercussions in all its elements (demand, supply and ground operations). Further, this industry will continue to be in constant transformation, and its future is uncertain.

The planning and design of an airport terminal is a complex process that faces many unknowns, which, if incorrectly accounted for, may lead to considerable costs. Conversely, "the prevention of design errors for a single airport terminal can amount tens of million dollars in savings". (Svrcek, 1994) Naturally, it is necessary to incorporate future uncertainties in the planning and design of airport infrastructure. This is the main focus of this dissertation.

Layout definition is an important step in the planning and design of an airport terminal. It is, therefore, crucial to create a selection methodology that takes into account the uncertain future of airport transportation. The main objective of this work is, therefore, the selection of a robust layout for the airport terminal, that is, the identification of a layout concept that minimizes the impact of the changes inherent to the air transport industry. To achieve this goal it is important to develop a methodology that integrates the uncertainties from the beginning of the process.

# 2. STATE OF ART - UNCERTAIN INTRODUCTION IN AIRPORT PLANNING

There are several projects and methodologies that incorporate uncertainties in airport planning and design that oppose to traditional planning<sup>1</sup>. These projects focus on two distinct concepts: Real Options (RO), Robust Design (RD) and scenarios methodology.

<sup>&</sup>lt;sup>1</sup> Planning based upon a single forecast of future traffic demand.

The RO concept analyses the future from a financial point of view, and can be understood as a financial tool. However several authors have introduced this concept into traditional methods, particularly the Flexible Strategic Planning<sup>2</sup> and Dynamic Strategic Planning<sup>3</sup>. Both these approaches consider traffic values in the future airport as the main uncertainty, and do not incorporate any external factors to the infrastructure.

In contrast, the RD concept can be incorporated from the beginning of the planning and creation process, with the identification of noise factors as the starting point. There are examples of the application of this concept<sup>4</sup>; this thesis focuses in particular on the application of this concept to airport infrastructure. Its main purpose is to create a layout for the passenger building in which the changes in noise factors do not cause performance's disturbances.

Most authors consider as noise factors the operational elements that introduce uncertainties during the infrastructure's operation<sup>5</sup>. This thesis analyses the noise factors associated to the changes in air transport, which will determine the design and configuration of the airport terminal.

The scenarios methodology can be used in addition to the RD concept, which allows to create different visions for certain noise factors that will lead to the selection of a robust layout for the airport terminal. For the creation of scenarios, it is important to build a solid base of knowledge through literature review and interviews with key stakeholders, aiming to identify the main drivers of change. These drivers are the key point to the selection of the noise factors and to the beginning of the scenario planning.

#### 3. AIR TRANSPORT

Over time, the external environment changed air transport, with positive and negative impacts in its future development. To understand and identify the drivers of change it is important to analyse the past, present and future of air transport.

Taking the past and present behaviours of air transport into account, it is possible to divide the factors of change into five categories: macroeconomic, socio-economic, technological, political and legal, and environmental. These factors of change have an impact on three main elements of air transport (demand and supply of air transport, and ground operations), which also influence the design of the airport and its passenger terminal.

With regards to macroeconomic factors, two noise variables have been identified: rate of economic growth and fuel prices. Although both variables have an uncertain future behaviour, they have different impacts on air transport elements. Economic growth does not have a direct impact on the value of demand in developed countries, but may affect the economic development of airlines and,

<sup>&</sup>lt;sup>2</sup> Describe by Burghouwt (Burghouwt, 2007)

<sup>&</sup>lt;sup>3</sup> Developed by Neufville & Odoni (Neufville & Odoni, 2003)

<sup>&</sup>lt;sup>4</sup> Planning of Airport Platform Buses by (Diepen, Pieters, van den Akker, & Hoogeveen, 2009)

<sup>&</sup>lt;sup>5</sup> For example Svrcek created a tool to analyze the performance of layouts concepts to operation uncertainties (Svrcek, 1994)

consequently, the development of new business models. (CU, 2009) There is no directly proportional relation between fuel prices and tariffs applied to demand, since there are several measures implemented by airlines to minimize the impact of price volatility. Further, it is not possible to extrapolate the value of fuel surcharges from the behaviour of the fuels market. (CU, 2009) Finally, it should be noted that the elasticity of demand relative to the increase in tariffs' price is different depending on the market, route, distance and reason. (IATA, 2008)

In the variables that compose the socio-economic factors, the changes in population behaviour stand out. Although in developed countries the age and economic structure of the population will not suffer big changes, the population's needs and behaviours may change, leading to the adjustment of supply and airport infrastructure.

Technological changes may occur at three levels: aircraft, ground operation, and traffic control. It is uncertain which technologies will succeed, but it is possible to determine the possible paths. In particular, at the level of aircraft technology the main objects of ongoing investigation relapse on improving energy efficiency, the capacity and speed, which is reflected on the size and operating characteristics of the aircraft. New technologies of ground operations are the main focus on monitoring and processing of passengers and baggage, where the uncertainty is associated with the dimensions needed for new mechanisms and their processing fees. In terms of air traffic control technology, the doubt is when more effective monitoring and coordinating mechanisms are going to be implemented.

Regarding legal and political factors, specifically security policies, it is not possible at present to determine whether the future will lead to a more or less restrictive policy, derived from conflicts between nations and acts of terrorism.

As for environmental factors, the measures to mitigate the emission of greenhouse gases (GHG) stand out. These may involve responses in the technological, operational, strategic and economic level. Therefore it is unpredictable when and what policies will succeed and in what proportion.

#### 4. THE AIRPORT TERMINAL

The airport terminal is a dynamic system that supports pedestrian (passengers, visitors, employees, etc.), vehicles, aircraft, cargo, and baggage flows and establish the relation between the landside and the airside (Wells & Young, 2004). The dimensioning of this structure is mainly dependent on the characteristics of the passengers and airlines it serves.

The passenger flow's composition is not uniform; there are passengers with a diversity of behaviours and characteristics that affect the dimensioning of functional areas. Further, the business model of airlines affects the terminal dimension and design.

The dimensioning of passenger processing areas, including those of check-in, security check and passport control, is conditioned to the average processing time associated with the services provided. These average processing times should take into account the maximum queuing time allowed for passengers and the amount for the minimum time of arrival prior to the departure of the aircraft determined by the airlines. The size and average time for processing a given area affect the sizing of

the next processing area. For example, the design areas for inspection of safety are contingent upon a average processing rate (time per passenger) from the check-in.

The layout of the passenger terminal may have several configurations, but takes into account certain concepts that serve has basis to its structuring: Linear Terminal, Finger Pier Terminal and Satellite Terminal. Complementary, there is the concept of Transport, which can be applied individually but it is usually associated with one of the other concepts.

# 5. SCENARIOS

Air transport elements, such as supply, demand and ground operations, are subject to a multitude of changes, but only a few variables are responsible for the terminal's uncertain future. The scenarios methodology is based on noise variables identified for each drive/factor of change, which have a variety of future hypotheses. Namely, the positive evolution of a specific noise variable is not directly accompanied by air transport growth, specifically the world traffic growth. The scenario construction takes into account long-term perspectives, that is, about 30/40 years. For this reason, different levels of variables' evolution must be considered.

		Evolution Hypotheses		
Factor of Change	Noise Variable	Small	Moderate	Strong
Macroeconomic	Economic growth rate	A1	A2	A3
	Fuel price	B1	B2	B3
Socioeconomic	Population's needs and behaviors	C1	C2	-
Technological	Aircraft	D1	D2	D3
	Ground Operations	E1	E2	
	Air traffic control	F1		F3
Politic and legal	Security Policy	G1	G2	
Environmental	Measures to mitigate GHG emissions	H1	H2	H3

 Table 1 - Evolution hypotheses for each noise variable

Evolution hypotheses are identified for each noise variable, considering its small, moderate and strong variation. But it is important to note that not every variable has tree possible evolution paths. Although the combination of evolution hypotheses leads to 1296 scenarios<sup>6</sup>, there are combinations that not represent possible scenarios. The factors of change are related and interdependent, consequently the behaviour of a particular factor has an impact on several variables and elements of air transport. The analysis of these relationships results in the identification of 17 contradictions, which reduce to 30 the number of plausible combinations. For example, if there are changes in security policy occur, there will be repercussions in the technologies used in ground operations. So scenarios combinations with G1 (restrictions in security policy) and E1 (no changes in ground operations) must be eliminated.

The construction of scenarios is based on plausible combinations and aims to identify two extreme and one intermediate scenarios. The selected ones are the three more representative of future

<sup>&</sup>lt;sup>6</sup> Scenario is a combination of Ai, Bi, Ci, Di, Ei, Fi, Gi and Hi

changes, that is, which cover a broader range of hypotheses. It should also be noted that the rate of economic growth affects the family of scenarios where each combination is located.

**Minimum Scenario -** The starting point of this scenario corresponds to a (nearly) stagnant economic and technological development, with exception of ground operational technologies, which will be driven by a strong and restrictive security policy. Fuel prices will have a reduced growth, and the needs and behaviours of passengers will be similar to present ones.

**Medium Scenario -** A moderate economic growth, followed by an increase in fuel prices, will stimulate air transport supply and demand and technological evolution. Aircraft technology will have a modest evolution that consists in different-sized aircraft, but fleet replacement process will be moderated. Emission trading schemes will only be applied in the EU and the US, and the incorporation of alternative fuels in aircraft will be partial.

**Maximum Scenario -** With a strong economic growth, and extreme increase in fuel price, there is a high technological evolution, especially in aircraft's technologies. In particular, this scenario is characterised by aircrafts with better energy efficiency and lower processing times (new processing methods). The worldwide application of new measures to mitigate GHG emissions (world emission trading schemes), followed by a strong incorporation of alternative fuels, will also increase technological development.

# 6. ROBUST LAYOUT FOR THE AIRPORT TERMINAL

The various scenarios are reflected in different ways in the different air-transport element and, consequently, in the airport terminal. Depending on the particular future scenario in question, we can identify several airport-terminal requirements, which form the basis for evaluating the passenger building and correspond to a combination viewpoint for evaluation. We identify eight of these requirements (**Figure 3**) and seven evaluation viewpoints (**Figure 2**). Note that each requirement is associated with various evaluation viewpoints that are quantified by the evaluation of specific indicators..

The evaluation process begins with a qualitative analysis of each layout concept for the terminal according to the different evaluation viewpoints and with a posterior quantitative analysis of the correspondent indicators. The quantitative evaluation of each indicator is possible by creating value functions representative of the performance / attractiveness of the different configurations in each indicator.

The generalised logistic function or Richards function was identified in Martinez, Viegas e Eiró (2011) as a shape that allows a much better fit for reproducing spatial interaction phenomena at local scale. This function is a widely-used for growth modelling (Wikipidea, 2011) and was initially proposed by Richards in the field of Botany to reproduce empirical data on the growth of plants (Richards, 1959): The Richards function shape "an initial range of small loss of attraction (the "near" range), followed by a range of steep loss of attraction (the transition from "near" to "far"), and finally another range of

already rather low attraction, but with low marginal loss (the "far" range)" (Martinez, Viegas, & Eiró, 2011). Following this reasoning, this function is studied and calibrated in order to represent the relationship between the change in attractiveness of the airport terminal layout when confronted with a specific indicator.

**Equation 1 - Richards function expression** 

$$f(x) = A + \frac{K - A}{(1 + Qe^{-B(x-M)})^{1/\nu}}$$

A: the lower asymptote; K: the upper asymptote. If A=0 then K is called the carrying capacity; B: the growth rate; v>0 : affects near which asymptote maximum growth occurs; Q: depends on the value Y(0); M: the time of maximum growth if Q=v Source: (Wikipidea, 2011)

This function, after calibration of B and Q values, allows a better fit between the mathematical results and the attractiveness value of each indicator, with the advantage of not having any discontinuities or abrupt jumps throughout its domain.



Figure 1 - Indicator 1 Function Value - Passengers Walking Distance. source: author

For example, for indicator 1 - passengers walking distance is possible to establish through the calibration of Richards function represented in the following image. The figure 1 demonstrates a lower attractiveness of the airport terminal when passenger walking distance increase.



The value of each layout configuration in each indicator is express in the fallow figure.

Figure 2 - Evaluation of layouts per viewpoint. Source: author.

- 1 Passenger walking distances
- 2 Ease of creation of specific circuits
- 3 Ease of conversion of specific
- areas to LCC passengers Ease of conversion/adaptation of
- 4 functional areas Legibility of the airport terminal
- 5 (change of direction, path
- complexity) 6 Ease of terminal expansion
- 7 Dimension and features of aircraft
- parking spaces
   Degree of separation between
- <sup>8</sup> departure lounges

It is evident that the quantitative assessment of each concept is different depending on the point of view under scrutiny. While the linear terminal has the highest number of viewpoints with high ranking, the selection of the robust terminal is realized based on requirements that are composed by the viewpoints, so the simple evaluation of these points may not express the predominance of the linear layout.

The identification of quantitative values for each requirement is made under the hypothesis that every viewpoint contributes differently for the evaluation of a specific requirement. Consequently, to determine the partial value of requirement is necessary to take into account the weight of each point of view in each requirement. Within a holistic transcription of what was possible to apprehend about the importance of each of this aspects along this dissertation, the weight of each requirement was arbitrated.

However, following the quantitative evaluation of each layout, it is clear that there is no predominant concept (Figure 3); none of the concepts responds with high level of satisfaction to all requirements. However, the requirements have different levels of importance, being the responsibility of the decision-maker to define a hierarchy for the requirements.



- a Different levels of adaptation to LCC
- b Different traffic volumes and compositions
- c Different numbers of passengers processed in control areas
- d Different numbers of business frequent flyers
- e Different aircraft sizes and types of processing
- Different passenger capacity per plane
- g Different volume of aircraft/hour in the terminal
- h Different number of passengers performing check-in and processing luggage

Figure 3 - Evaluation of layouts per requirement. Source: author.

This hierarchy can be accomplished through a multi-criteria methodology of decision support. The requirements are interpreted as criteria, fundamental in the choice of robust terminal. The hierarchy is crucial to the selection of robust terminal because it is conditioned to the requirement weight in the Evaluation global value of the airport layout concept.

The global value for each layout concept can be calculated as follows:

Equation 2 - The global value of the layout evaluation

Global value of the layout 
$$i = \sum_{j} K_{j}(i) V_{j}(i)$$

- i Layout concept valued (Linear, Finger piers or Satellite)
- j Variable requirements according to future scenarios
- K<sub>j</sub> Standard weighting of requirement j
- V<sub>j</sub> Partial value of the layout i per requirement j

source: author

In this dissertation, the hierarchy is based on the sensitivity degree of the requirements to the uncertain scenarios. If the requirements' hierarchy is performed taking into account their sensitivity degree to changes in the three scenarios identified, the satellite terminal concept has the highest global value, and must be considered more robust than the others.

 Table 2 - Global value of evaluation when taking into account the sensitivity degree of the requirements to changes expressed in the scenarios

	LINEAR	FINGER PIERS	SATELLITES
Global value of evaluation	0,47	0,68	0,74

It is relevant to highlight the importance of prioritizing requirements, which represents a decision criterion that can be different from decision-maker to decision-maker. In particular, we can identify different hierarchies depending on the airport strategy: low-cost airport terminal, traditional airport ("top of the line") or a mixed airport. For example, if the strategy for the airport is to attract low-cost companies (low-cost terminal), the requirements a and d ("different levels of adaptation to LCC" and "different numbers of business flyers") should have higher weights. Consequently, global values of evaluation will be different depending on the airport strategy, as we can see in the table 3.

Table 3 - Global value of evaluation when taking into account different airport strategies.

	LINEAR	FINGER PIERS	SATELLITES
Low-cost airport terminal	0.54	0.34	0.24
Traditional airport ("top of the line")	0.52	0.76	0.71
Mixed airport	0.52	0.67	0.70

Depending on the position taken by the decision-maker layouts will have different global values, as can be seen in the table above. However, it is important to emphasize that finger piers configuration is normally close to the maximum global value or is the highest value across the airport strategies analyzed.

# 7. FINAL CONSIDERATIONS AND FUTURE DEVELOPMENTS

After the development of this dissertation, it is important to highlight several concluding considerations that support decision-makers and planners involved in the planning and design of a terminal. These final considerations can be divided into two parts with regard to their genesis. On one hand, we highlight methodological considerations that are, as the name suggests, related to the methodological approach to the selection of the robust terminal layout. On the other hand, we describe the robust airport terminal layout selected, the final product of this dissertation.

# Methodological considerations

The planning and design of airport terminals faces many uncertainties. Currently, there are several methodologies that, in contrast to traditional planning, integrate future uncertainties during the development of these infrastructures. However, most methodologies consider traffic volume as the main uncertainty, and do not incorporate external factors to the infrastructure.

Comparing and confronting the concepts to different scenarios for the main noise variables can evaluate the robustness of the different terminal layout concepts. The selection of noise variables is a crucial point in the selection of robust layout, so it is important to create a solid base of knowledge.

The creation of scenarios starts with the definition of evolution hypotheses for the several noise variables. The crossing of evolution's hypotheses creates a large number of scenario combinations that, confronted with several contradictions, originate plausible scenario combinations. Taking into account the methodology optimization and operation, it is important to define a restricted number of scenarios that cover the largest possible number of hypotheses.

The requirements that vary according to the future scenarios are the basis to evaluate layout concepts and are composed of evaluation viewpoints. The qualitative assessment of each concept is different depending on the viewpoint in analysis, but the isolated analysis of each point is not indicative of the robust layout. Instead, the robust layout is determined by calculating the global value of evaluation for each concept. This global value is the sum of partial values of each requirement determined by the valuation attributed to each point of view. However, not all requirements have equal weight in the global-value estimation, which is why it is important to prioritized requirements.

The global value attributed to each layout concept varies according to the importance attached to each requirement, so depends on the requirements' hierarchy. Consequently, the robust layout depends on the decision-maker or the market orientation of the airport company.

#### The selected robust layout

The decision maker has an important role in the selection of robust layout for the airport terminal because he or she defines the level of importance of each requirement in the evaluation process. These requirements are evident in the characteristics that the passenger terminal layout will have to respond to in the future. Consequently, the ranking of requirements can be realized taking into account their sensitivity degree to various future scenarios.

The requirements with high sensitivity degree are associated with different volumes and compositions of traffic and different values of passenger capacity per aircraft. When considered the sensitivity degree as the hierarchy criterion for requirements, the satellite terminal layout concept has the highest global value, and must be considered the most robust.

When taken into account different airport strategies we have different optimum layout. Within these different airport strategies there's no layout concept with a maximum global value in all positions. However, the finger piers terminal stands out since it seems to be acceptably good, always close or equal to the maximum value.

#### **Future developments**

Throughout the development of this work, new ideas and questions emerged; they should be pointed out since they can be regarded as starting point for future developments.

Regarding the scenarios methodology, it is important to consider in depth the role of different actors in the development of the various scenarios, identifying and creating their vision for the future. Further, the analysis of airport-terminal layouts can be extended to hybrid configurations, which are based on the three basic concepts identified.

In this work the layout analysis only considered future scenarios. However, it would be interesting to incorporate the present requirements of the airport terminal.

Finally, it would be important to integrate an economic perspective in the study by including costbenefit analysis in the methodology of robust-layout selection.

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