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Conceptual Framework for the Implementation of Flexibility

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Depicting Flexibility

The term "flexibility" is adopted in this study. This is the term that is adopted by the majority of the authors and it is widely used in the literature as stated above. **Flexibility is herein defined as the ability to alter an infrastructure in time to respond to its capacity needs with maximum value for money of investment used.**

This definition is inspired in some of the definitions presented above. First of all, flexibility is also seen as an ability which means that is an intrinsic characteristic of a system. It is also adopted the perspective of Groak (1992), Morlok and Chang (2004), de Neufville (2008), Zhang et al. (2008) and Shuchi et al. (2012) that the infrastructure should be as changeable as possible to meet the new requirements or expectations. Therefore, it has to be ready to be implemented in time to respond to these changes. It is also considered that flexible means to be removable too, if necessary. Since flexibility helps to deal with unexpected events, when the events change or are no longer an issue it should be possible to change this feature or even remove the flexible option in use. Flexibility is expected to provide maximum value for money of investment used to respond to capacity needs. In order to achieve this, not only the costs have to be minimized but the productivity results have to be good. So, similarly to Nelson et al. (1997), Morlok and Chang (2004), Zhang et al. (2008), and Taneja et al. (2012), flexibility is herein understood as a feature that highly influences the airport productivity. Moreover, the costs are also included in the definition as the perspective of Nelson et al. (1997), Saleh et al. (2001), de Neufville (2008), Zhang et al. (2008) and Taneja et al. (2012) is understood as very important. Flexibility should assure that the adaptations are done with maximum value for money of the investment to represent an advantage.

According with Beeferman and Wain (2012) an airport is an infrastructure. These authors define an infrastructure as "facilities, structures […] that are the basic physical and organizational capacities and resources needed for the operation of a society or enterprise or are necessary for an economy to function." The definition is broad and subject to interpretation. However, as the airports are pointed as an example of an infrastructure by the authors, for the purpose of this work the airport will be considered as the infrastructure. The features of the airport such as runways and terminals are considered as components of the infrastructure.

Flexibility can be applied in different moments of airports' development and to different components with different objectives, as presented in Figure 1. The three different moments of change are highlighted by numbers from 1 to 3, whose objectives are the following:

1) Extension, which is related with using flexible options to delay the moment to expand an infrastructure's component by boosting its capacity for a certain period;

2) Expansion, which represents the building of a new infrastructure's component or the enlargement of an existing one with flexible options;

3) Reduction, which means to use flexible options to reduce the capacity provided by one of the infrastructure's component when demand is lower than expected.

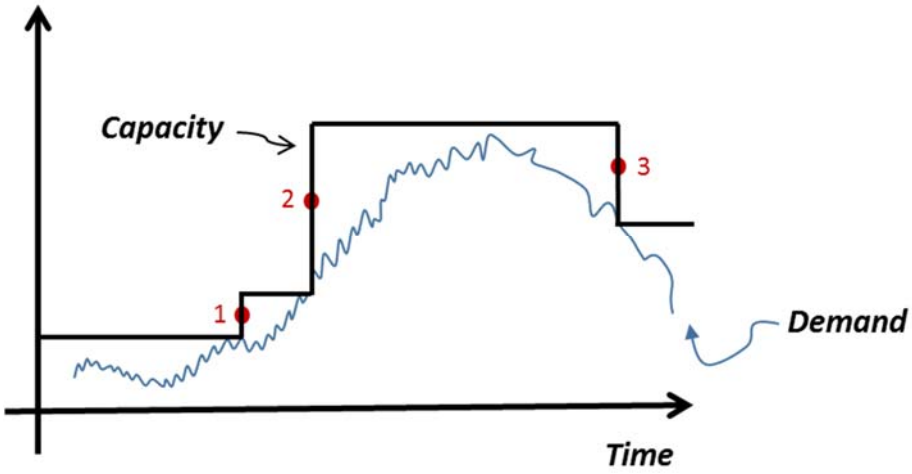

Figure 1 - Different moments to apply flexible options

Flexible options can vary according to the change moments to apply flexibility as the objectives in each moment are different. **A flexible option is herein understood as a solution that allows airport managers to alter the capacity of a certain infrastructure's component in time to respond to a certain need, with maximum value for money of investment used, and stop its use when it is no longer necessary**. Table 1 gathers some of the most common flexible options mentioned in the literature. Most of the flexible options were collected from the work presented in Magalhães et al. (2013), where the authors reviewed several journal articles and other publications related with airport flexibility cases studies. The goal of this categorisation is to divide the flexible options according to their focus, or by other words, based on the type of feature at which they will act to alter capacity.

Table 1 - Flexible options according with the type and the moments to apply flexibility

	Type of Flexible Options	*Technological and Equipment options*	*Procedure options*	*Building options*
Moments to	**Extension**	Moving systems: check-in counters, airline counters, security areas, and luggage belts	Swing gates between international and domestic flights	Available spaces (buffers) at the terminal Moveable partition walls at the terminal to alter the capacity of

				some areas within the terminal to increase or reduce the capacity for aeronautical processes (e.g. retail areas)
	Expansion			Available land for future expansion, which can be used for non-aeronautical activities (e.g. solar panels, warehouses) meanwhile Linear form of terminals Modular terminals for easier expansion Open space terminal: minimum load bearing walls and high roof span of the terminal
	Reduction	Moving systems: check-in counters, airline counters, security areas, and luggage belts	Swing gates between international and domestic flights	Moveable partition walls at the terminal to alter the capacity of some areas within the terminal to increase or reduce the capacity for aeronautical processes (e.g. retail areas)

Most authors have been study the application of flexibility in expansion, as stated in the previous chapters (de Neufville and Odoni, 2003; Burghouwt, 2007; de Neufville, 2008, Kwakkel et al., 2010; Gil and Tether, 2011). In this case, airport managers are building a new infrastructure's component and flexible options are being used to cope with uncertainty and most likely, building in phases instead of having a very large infrastructure from the very beginning when demand is not as higher as expected in the future. The reduction case has not been study but it is important to consider as some infrastructures are larger than needed, representing a high cost for airport managers. This is the case of the Montréal-Mirabel International Airport in Canada, which is a huge infrastructure with a very low demand. It was converted into a cargo airport but a significant part of the infrastructure is closed. Flexible options can help by reducing the capacity for aeronautical processes to create more areas with for other services and functions (e.g. retail).

The focus of this thesis is the extension case where flexible options help airport managers to do more with less or, by other words, to increase their infrastructure's component capacity for a little longer and delay the need to expand it. By adopting a flexible development, airport planners can maximize the use of the terminals by exploring their capacity until its maximum. In a flexible development situation, capacity is coordinated with demand for all time scopes. Small capacity investments are stimulated instead of high investments that will take years to be fully used. This represents the flexibility's aptitude to explore the capacity and reducing the idleness. As demand evolves, the limits of flexibility are progressively depleted and the available capacity is exhausted. There will be a moment in which the infrastructure's component will no longer be able to cope with demand. At this moment, additional flexibility must be provided, which entails substantial investment in expanding the infrastructure's component. In the meantime, with a flexible development, airports managers avoid premature expansions and minimise the need for investments.

An airport terminal might be considered to be congested but typically, that same terminal still has a certain capacity which is not being explored. This remaining capacity will now on be specified as latent capacity. Flexible options allow airport managers to explore this latent capacity. These options will delay the decision of expanding the terminal by exploring its capacity until the physical limits are reached.

It is patent that flexibility is closely linked with time. As explained above, different time scopes (or stages of airport development) require different types of flexible options. Although the benefits of flexibility have been mentioned by several authors, the studies on how to measure them have been scarce. Moreover, it is important to remind that flexible options represent a cost for airport managers. Therefore, the benefits of flexibility have to be weighted in the face of the cost that is assuring the options are providing maximum value for money. As long as the benefits produced by the flexible options overcome its costs, flexibility is useful. However, there is a moment when flexible options might be more expensive than the benefits produced. This is especially important when flexible options are applied with an extension objective, meaning to delay expansion. There will be a moment, if demand continues to increase, where airport manager must go for expansion instead of using flexible options with extension as a goal.

Figure 2 represents the interaction between flexibility, external factors and airport operations. This figure is the starting point of this research, which is the understanding of flexibility in this study. This figure can be divided into three main blocks:

- External factors – drivers of the need for flexibility that were identified by some authors (Slack, 1987; de Neufville and Belin, 2002; de Neufville, 2008; Wijnen et al., 2008; Magalhães et al., 2013) and presented in sub-chapter 1.2;
- Airport operations - represented through processes (e.g.: passenger or cargo). It is where flexibility is applied. Each process is an organised chain of tasks (e.g.: screening, loading). Each one consumes time and resources (costs). Tasks may be shared by different processes (e.g.: check-in). The utilisation of processes is justified as they define the performance and are a key component on the cost structure of the airport. Flexibility works by influencing the required resources to do a task;
- Airport performance (Outcome) – represents the outputs produced by the airport which are influenced by flexibility. As stated above, the two main productivity parameters considered by the authors to analyse of flexibility are throughput – performance in its broad sense – (Nelson et al., 1997; Zhang et al., 2003; Morlok and Chang, 2004; Taneja et al., 2012), and financial productivity (Nelson et al., 1997; Saleh et al., 2001; Zhang et al., 2003; de Neufville, 2008; Taneja et al., 2012). Flexibility influences the production of processes and, ultimately, the performance and cost structure of the airport.

Flexibility can be applied at different levels of development: components, building design, space design and master plan. This labelling is deeply inspired in the work of Butters (2010). It has a strong similarity with the levels of flexibility proposed by Slack (1983) and Koste and Malhorta (1999) for manufacturing flexibility. These levels can be connected with the typical planning levels: strategic, tactical and operational. The connection established is influenced by the work of Magalhães et al. (2013) where the most common flexible options for each level are divided among these three levels. Some levels of flexibility are shared by two planning levels, depending on the type of flexible options.

Hereupon, strategic level gathers master plan and space design, tactical level space design and building design, and operational level gathers the building design and components.

This figure helps to explain the rationale behind one of the hypothesis of this thesis, that is: flexibility allows adjusting the processes according to the needs and therefore, increasing the airport productivity, or at least keeping its values in order to delay the need for expansion investments.

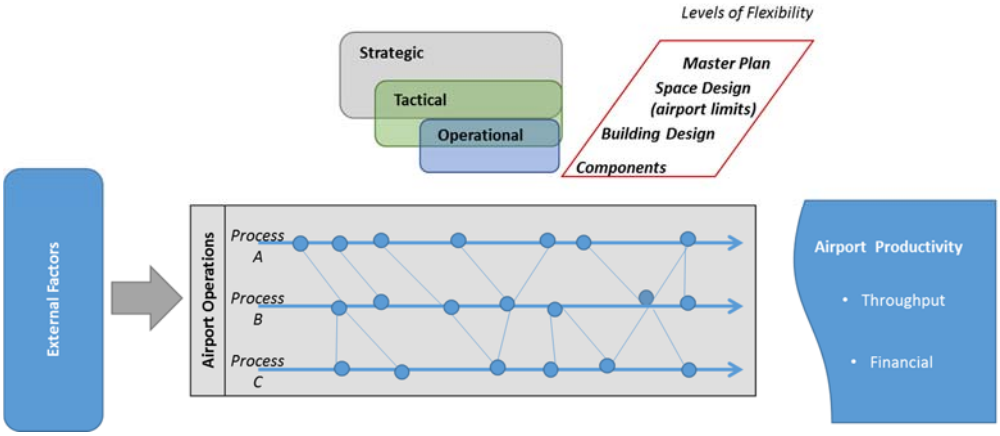

Figure 2 - The interaction among external factors, airport operations and flexibility

Flexibility allows balancing costs, productivity and capacity (Figure 3). As several authors stated (de Neufville and Belin, 2002; Burghouwt, 2007; de Neufville, 2008, Gil and Tether, 2011, Magalhães et al., 2013), whenever conditions change it is necessary to adapt capacity and consequently, the system's productivity will suffer changes with an associated cost. Flexibility is the asset that allows matching the needs with the system's capacity. However, as several authors mentioned (Nelson et al., 1997; Morlok and Chang, 2004; Zhang et al., 2008; Taneja et al. 2012), by changing the system's capacity with a certain cost, the system's productivity will also change. It is possible that the productivity remains stable, but is unlikely.

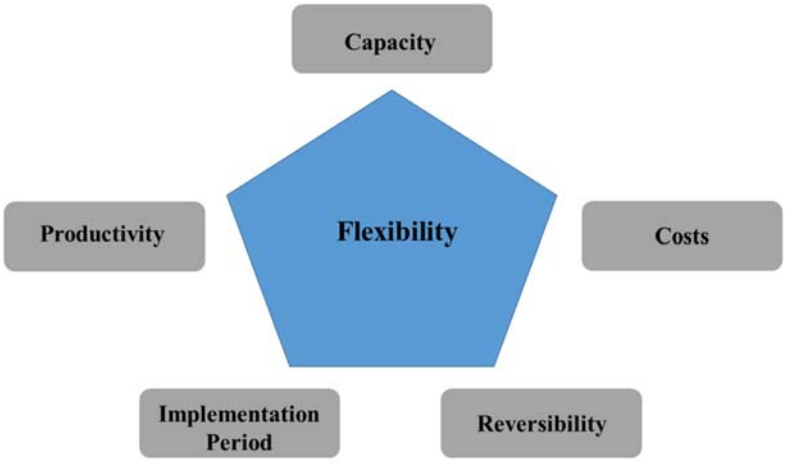

Figure 3 - Fundamental variables of Flexibility

The understanding in this work is that besides costs, productivity and capacity, flexibility needs two more variables to be fully characterised, namely: implementation period and reversibility. The implementation period differs between flexible options. The possibility of being reversible is important to understand whether an option can be dismantled or not. This is the rationale behind one

of the hypothesis of this work, which is that flexibility can be characterised by five fundamental variables: cost, productivity, capacity, implementation period and reversibility.

Conceptual Framework

The implementation of flexibility in airports, as explained in the previous chapter, has been dispersed and mostly based on the skills and knowledge of the airport managers. Therefore, a new methodology for the implementation of flexible options was developed and it is herein presented (Figure 4). This methodology was developed for the implementation of flexibility for extension purposes. Thus, even before applying this methodology it is necessary to understand if we are considering flexibility for extension purposes. If it is the case, we can proceed. If it is not, we should not use this methodology as it was developed for this specific case. This methodology has three different phases:

- **Setting the Scene Phase** – this is the phase where all the decision inputs are defined and the scene is set. It has two main parts: the determination of the decision inputs and, the choice of scenarios and flexible options.

    - Decision inputs: airport managers have to decide the scope of the work and the period of analysis. The scope is related with defining which parts of the airport will be analysed. Is it the whole airport? One of the passengers' terminal? The check-in area? As stated above, flexibility can be applied at different levels, from strategic to operational, with different types of options (Koste and Malhorta, 1999; Butters, 2010; Magalhães et al., 2013). Therefore, the use of flexibility has to fit the scope as different types of flexible options can be found for each scope. The period of analysis is important to define as it will influence the scenarios which will be used in the study. An analysis for a season generates different scenarios when compared with a 5-year period of analysis. Thus, it is necessary to define with precision the analysis period. The decision variables are chosen by the airport manager. The reason to let the airport manager choose the decisions variables is that flexibility has been linked with costs savings, time reductions and increase of performance (or robustness towards change) as explained above. But there is no common understanding of what variables should be used to analyse it. So, by letting the airport manager choose the decision variables we are specifying this methodology for each particular airport. However, the decision variables have to reflect the processes at the terminal for passengers and luggage. The objective of this methodology is to analyse the benefits of flexibility for extension. Thus, the variables have to reflect what is going on inside the terminal in terms of capacity, productivity and costs of the processes.

    - Scenarios and Flexible Options Choice: the main sources of uncertainty shall be identified and the possible future scenarios defined. As explained above, air transport is a highly dynamic business with several sources of uncertainty (de Neufville and Belin, 2002; de Neufville, 2008; Magalhães et al., 2013). These uncertainties leave airports in a difficult position to respond to it by changing quickly. For each scenario, the suitable flexible options to deal with it shall be identified to be evaluated in the next phase, according with the scope of the study. If possible, each scenario should have an associated probability of occurrence. This information will be helpful for the airport manager in the next phase, as if there is a scenario with a high probability of

occurrence when compared with the others, it might be wiser to choose the flexible option with the best results in this scenario instead of one that presents good results for all scenarios. Flexible options can be diverse. However, the most common ones were already presented in Table 1. As different scenarios require different flexible options, it is important to evaluate (in the next phase) the results obtained for each alternative in each scenario in order to choose the one which produces the best results. Yet, to achieve this, is important to list the uncertainties, to develop the scenarios and list the flexible options to respond to them.

- **Ex-ante Operational Evaluation Phase** – this is first evaluation, where the flexible options will be evaluated for each scenario in order to understand if they provide better results than the "do nothing" option, which means to leave things as they are. This phase requires information from the previous one. We adopted the vision proposed by other authors (Brill and Mandelbaum, 1989; de Neufville, 2008; de Neufville and Cardin, 2008; de Neufville and Scholtes, 2011; Eckart, 2012) that flexibility can be evaluated through the comparison of different scenarios. The values of the decisions variables for the base case, which corresponds to the case of testing the current features for the scenarios, have now to be estimated as well as for each flexible option in each scenario. Regarding the evaluation method, it has to be chosen based on the analysis period and the scope itself defined in the previous phase. Long-term analyses are typically based on pre-investment analysis whereas short-term analyses related with airport daily operations are usually analysed with simulation methods. Therefore, the aspects defined in the previous phase will influence the following steps and the type of analysis performed. In Eckart (2012) several methods used to analyse flexibility are presented. Moreover, it has to be taken into consideration if it is possible to associate a probability of occurrence to each scenario or not, as not all evaluation methods are able to incorporate probabilities. This phase serves the purpose of understanding if flexibility is an option to extend the capacity of the infrastructure's component from the inside and delaying expansion or not. Thus, at the end of this phase if flexible options do not provide better results than the "do nothing" option, which is the base case, the analysis should stop. This means that flexibility is not the answer to the problem. If it is not the case, we should proceed to the next phase. This evaluation is based on decision variables that are chosen by the airport manager, which for the purposes of this thesis will reflect the passengers' processes. To decide whether or not to proceed for flexible options, a matrix that compiles the obtained results for the decision variables for the base case and all the flexible options alternatives in each scenario is used. Figure 5 presents a generic matrix that provides an example for two different scenarios and *n* decision variables. Whenever the differences between the results obtained for the flexible options and the base case are positive (green), it is clear that flexible options will provide better results for that specific scenario.
- **Ex-ante Value for Money Evaluation Phase** – last phase is where the capacity extension portfolio of flexible options is produced. Once airport managers decide to proceed for flexible options, it is time to observe which flexible option provide the best results for each scenario. Airport manager might want to apply not the best flexible option for a specific scenario but the solution that offers good results for most scenarios. This methodology does not say to airport managers which option should be chosen. It only evaluates the results obtained for each flexible option in each scenario, pointing out the flexible options that provide the best results in each scenario. This evaluation is based on the probability of occurrence of each

scenario, if available, and the value for money that takes into account the cost of the flexible options and productivity results that are captured by the decision variables.

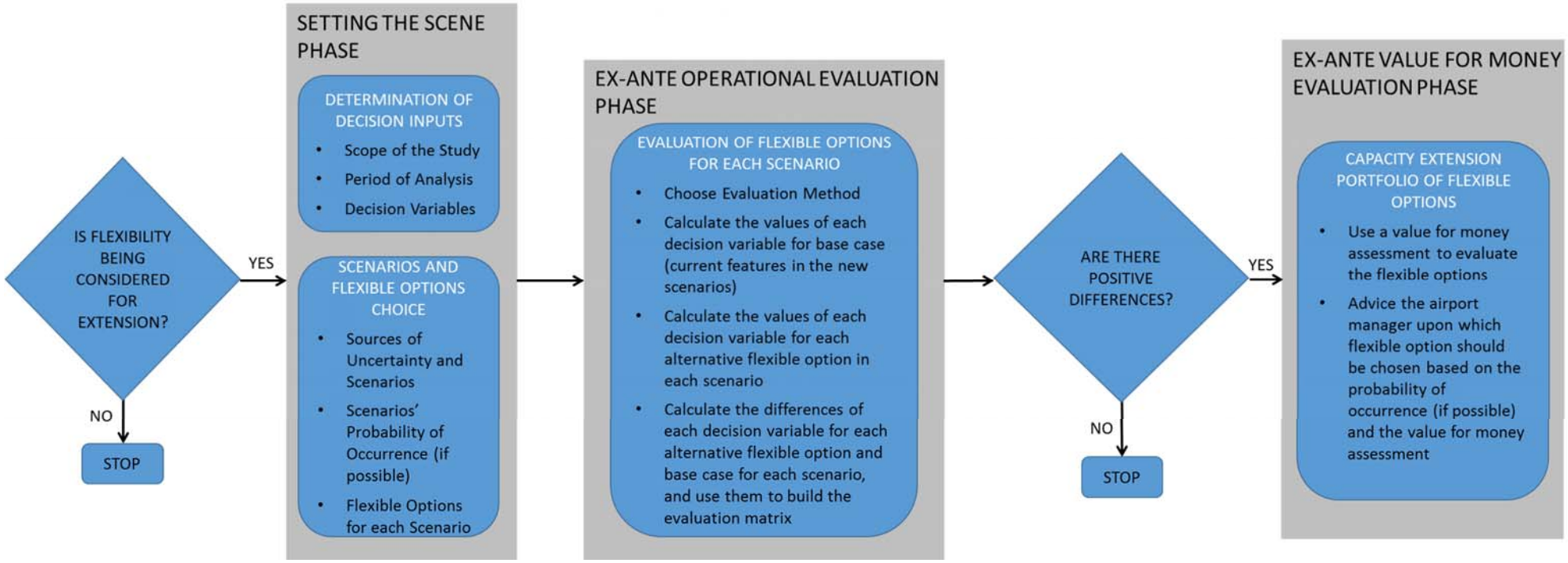

Figure 4 - Methodology for the Implementation of Flexibility

In Figure 4 is possible to observe that the first step is to understand if flexibility is being considered for extension purposes even before the methodology itself. The other methodology steps will now be described in detail for each specific phase:

1. **Setting the Scene Phase:**

1.1. Determination of Decision Inputs

1.1.1. *Define the scope* refers to the unit of analysis – (e.g. terminal, check-in area, etc.) – for which the flexible options will be analysed. As flexibility can be applied from strategic to operational levels (Magalhães et al. 2013), the scope definition is essential to assure the appropriate choice of flexible options. For example, if the unit of analysis is the arrival hall at passengers' terminal, moveable walls is a possible flexible option. However, if the unit of analysis is the check-in area we might want to consider options such as moveable check-in counters.

1.1.2. *Define the period of analysis* refers to define the time horizon (long-term, medium-term or short-term). This is important to define as it will generate different scenarios within the analysis time scope. For instance, a season analysis will only consider scenarios that can occur within a six-month period, for example. But a long-term period of analysis such as 5-years requires other type of uncertainties and therefore, different scenarios.

1.1.3. *Define decision variables* refers to choose the indicators that airport manager considers as the most important to take into consideration to evaluate productivity. As stated on the previous chapters, our understanding is that flexibility will influence the terminal processes in terms of throughput and financial results. So, decision variables are related with the processes for passengers and luggage. The IATA recommendation is that airport's capacity should be evaluated based on the level of service (IATA, 2004). As the level of service is focused on the aeronautical processes, the decision variables should be based on the indicators that allow planners to determine the level of service, such as the area per passenger and time spent in queue. Once the level of service is defined, planners only need to assure that the values of the decision variables are within the limits of that level. The Key Performance Indicators provided by Airports Council International are also a good option. Is possible to use both types of indicators as decision variables, as the decision variables can differ among airports. Different airport managers might have different perspectives on what are the main variables that should be consider in the analysis. Therefore, this methodology offers the opportunity to embed the analysis with specifications for each case. However, they will always have to reflect the processes for passengers and luggage. As for the number of variables, it varies significantly. Since the evaluation will be based on a matrix (Figure 5), as the number of variables increase so does the complexity of the matrix.

1.2. Scenarios and Flexible Options Choice

1.2.1. *Identify sources of uncertainty and consequent scenarios* refers to point out the relevant uncertainties and the consequent possible scenarios. This is mostly based on airport stakeholders experience and knowledge. The Delphi technique can be used here. This technique provides a platform where experts are invited to think and exchange their knowledge, through a multi-stage process based on questionnaires. Once the survey is completed, the questionnaires are delivered to the moderator who will compile the results and provide feedback to the participants. Participants might revise their answers in the next round. Each round allows improving the accuracy of the results. The process ends when a pre-defining stopping criteria or a certain result is reached (Tersine and Riggs, 1976; Schuckman et al., 2012). This can also be complemented with research on the evolution of similar airports in the literature. Some of the sources of uncertainty were already identified by other authors (de Neufville and Belin, 2002; de Neufville, 2008; Magalhães et al., 2013), thus time can be saved here. It will be unlikely to consider all the uncertainties and define the scenarios that might result from it. However, the goal should not be listing all the uncertainties and scenarios but the most relevant ones as it is not possible to predict all the possible future uncertainties and outcomes. This is a very time-consuming step but very important, as the evaluation method has to be able to reflect the scenarios that were define herein. Another possibility is to use scenarios already developed. For instance, RACE2050 compares and assess various visions and different policies that aim to key success factors for a sustainable growth. Concerning aviation, this study analyses how will changes in the global or regional economies impact the aviation passenger and cargo market. Two scenarios are presented: 1) Pink scenario – optimistic vision for 2030, where for air transport it is expected that airports of only regional importance will be transformed into business parks or logistics centres, and there will be a transition to electricity and hydrogen fuels that will be forced by regulations; 2) Black scenario – pessimistic vision for 2030, where for air transport it is expected that travel is only for those who can afford it the first option, despite delays and cancellations. Something for the global business class and not for average citizens (RACE2050, 2014). EUROCONTROL also provides several forecasts and scenarios for Europe for various time horizons. For instance, for 2035 EUROCONTROL presents four scenarios for air traffic: 1) Global growth; 2) Regulated Growth; 3) Happy localism, and; 4) Fragmenting world. Each scenario as different input assumptions, namely: economic growth, fuel prices, load factors, etc. that will lead to different volumes of traffic and patterns of growth (EUROCONTROL, 2013).

1.2.2. *Determine probability of occurrence (if possible)* refers to associate a probability of occurrence for each scenario. This is not mandatory to the success of this methodology. However, it is useful

because if a scenario has a high probability of occurrence when compared with the others, the airport manager might prefer to choose the flexible option that provides the best value for money for that scenario instead of one with average results for most scenarios. One common technique that can be used to determine the probability of occurrence is the Delphi technique. In the questionnaire, experts can be asked to assess the probability of occurrence of scenarios.

1.2.3. *List the possible flexible options for each scenario* refers to look at each scenario and define the flexible options that can be used to deal with it. The goal is to list the flexible options that would help to deal with each scenario. For each scenario, various flexible options will be tested in order to assess the one which produces the best results. As explained above, flexible options can be of various types. A flexible option is herein defined as a solution that allows airport managers to alter the capacity of a certain infrastructure's component in time to respond to a certain need, with maximum value for money, and stop its use when it is no longer necessary, to at least keep productivity stable towards change. Examples of the most common flexible options are presented Table 1.

2. Ex-ante Operational Evaluation Phase

2.1. *Choose the evaluation method* refers to pick one method to assess the base case (current situation) and the alternative flexible options. It can be picked from the ones summarised by Eckart (2012). The evaluation is based on the decision variables defined in 1.1.3. Thus, the evaluation method should reflect as outcomes the results for the decisions variables for the base case at each scenario, as well as the results of each alternative flexible option at each scenario. As explained before, the choice of the method also depends on the period of analysis and the scope. For long-term analysis with a strategic scope authors usually use financial analysis (de Neufville, 2008; de Neufville and Scholtes, 2011), whereas short-term analysis with an operational scope is more suitable for simulation modelling. Therefore, evaluation methods can be various as they have to suit the period of analysis, scope and decision variables. They vary from static indicators to complex simulation models. They can also be based on productivity and/or financial analysis.

2.2. *Calculate the values of the variables for the base case* refers to apply the evaluation method chosen on the previous step for the base case (which corresponds to the current features) under the different scenarios. Here, is where the results for the decisions variables for the base case in each scenario are calculated. These results are the base of this ex-ante operational evaluation and they will feed the following steps.

2.3. *Calculate the values of the variables for the flexible option of each scenario* refers to apply the same evaluation method used on the previous step to calculate the values of the decision variables for each flexible option of each scenario.

2.4. *Calculate the differences of each variable for each alternative flexible option relative to the base case, for each scenario* refers to use of the values obtained in 2.2 and 2.3, to calculate the differences between the values obtained for each flexible solution in each scenario and the base case. Once this is done, it is time to fill a matrix similar to the one presented in Figure 5. This matrix presents the differences for each flexible option and the base case for each scenario. If the difference is positive, it is marked in green. When the difference is negative is marked in red. It is important to notice that if one of the decision variables is a cost, a positive difference means that flexible options are producing worse results. So, in this case an inverse logic as to be used to mark the differences in red or green. Flexibility is also herein seen a relative attribute rather than absolute, as suggested by other authors (Chen and Chung, 1996; Koste and Malhorta, 1999). Thus, it is desirable to have flexible options evaluated with respect to another alternative or group of alternative solutions. It is important to observe that flexible options might repeat in different scenarios, as the same option can be used to respond to different issues. At the end of this phase, and using the matrix, airport manager has to decide whether to continue the analysis or not. If there are any positive differences, it is logical to proceed with the analysis. When the difference between the results obtained for the decision variables for the flexible alternatives and the base case in each scenario are positive, flexible options are a better option than the base case. Therefore, in this case airport managers should continue the analysis. The decision to proceed or not for flexible options will only take place in the next phase. This evaluation is an intermediate step where airport managers can check if flexible options are a solution for their capacity issues or not. Moreover, all the flexible options which do not present positive results should not be considered in the next phase.

3. Ex-ante Value for Money Evaluation Phase

3.1. *Using the value for money assessment to evaluate the flexible options* refers to use the value for money provided by each flexible option for each scenario to evaluate the options. Value for money is the term used to assess the maximum benefit from a good, feature or service. It measures the cost of that good, feature or service as well as the benefits obtained with that. So, at this point, for each flexible option of each scenario it is necessary to determine the costs for the period of analysis - set up, operation and maintenance, if applicable. If the period of analysis is long, it is necessary to update the costs to the reference year. To determine the value for money of each flexible option is necessary to weight the costs in face of the results obtained for the decision variables. It is important to remind that only the flexible options with positive differences in the matrix are being considered in this step.

3.2. *Advice the airport manager upon which flexible option should be chosen based on the probability of occurrence and the value for money assessment*

refers to use the results obtained in 3.1 to advice the airport manager. If the scenarios have an associated probability of occurrence, airport managers can decide to implement the flexible option with better value for money for the scenario with a higher probability of occurrence. However, if probabilities are similar it is wiser to choose a flexible option that provides good value for money for most scenarios, even if it is not the best in some of them. When there is no associated probability of occurrence, the flexible option that should be chosen varies for airport managers according with their experience and type of airport.

The flexibility of a system is herein seen as a relative measure. This vision is shared with other authors (Koste and Malhorta, 1999; Chen and Chung, 1996). This means that it can only be compared against the flexibility of other systems. The flexibility of an airport is analysed in this dissertation through the comparison of different scenarios, by assessing their performance and costs or other aspects decided by the airport manager. The comparison of different scenarios to measure flexibility was suggested by several authors (Brill and Mandelbaum, 1989; de Neufville, 2008; de Neuville and Cardin, 2008; de Neufville and Scholtes, 2011; Eckart, 2012).

			BASE CASE FOR SCENARIO X				BASE CASE FOR SCENARIO Y			
		Decision Variables	DV_1	DV_2	...	DV_n	DV_1	DV_2	...	DV_n
SCENARIO X	*Flexible Option A*	DV_1	Δ+				Δ+			
		DV_2		Δ+				Δ+		
		...			...				...	
		DV_n				Δ+				Δ+
	Flexible Option B	DV_1	Δ+				Δ-			
		DV_2		Δ+				Δ-		
		...			...				...	
		DV_n				Δ+				Δ-
SCENARIO Y	*Flexible Option B*	DV_1	Δ-				Δ+			
		DV_2		Δ-				Δ+		
		...			...				...	
		DV_n				Δ-				Δ+
	Flexible Option C	DV_1	Δ+				Δ-			
		DV_2		Δ+				Δ-		
		...			...				...	
		DV_n				Δ+				Δ-

Figure 5 - Matrix to Support the Ex-ante Operational Evaluation

So far, flexible options have been used *ad hoc* without any robust or systematic approach. This methodology intends to overcome this limitation by proposing a new approach for the implementation of flexibility. This methodology allows assessing the immediate need for flexibility. However, it does not mean that if the need is not immediate the airport manager should not implement flexible solutions. This method provides an organised approach for the implementation of flexibility. Moreover, the general nature of the framework means that it can be applied in other contexts and other components of airport besides terminals.

References

Beeferman, L.; Wain, A. (2012). Infrastructure: Defining Matters. Harvard Law School. Available at: http://www.law.harvard.edu/programs/lwp/pensions/publications/INFRASTRUCTURE%20DEFINING%20MATTERS%20FINAL.pdf (last accessed November 14, 2014).

Brill, P.H.; Mandelbaum, M. (1989). On measures of flexibility in manufacturing systems. International Journal of Production Research, 27:5, 747-756.

Burghouwt, G. (2007). Airline network development in Europe and its implications for airport planning. Ashgate, Hampshire, England

Butters, M. (2010). Flexible Airport Design. Airport Management, Vol. 4, No. 4, 321-328, July-September, Henry Stewart Publications, 1750-1938.

Chen, I.J.; Chung, C.-H. (1996). An Examination of Flexibility Measurements and Performance of Flexible Manufacturing Systems. International Journal of Production Research, 34:2, 379-394.

de Neufville, R. (2008). Low-cost Airports for low-cost airlines: flexible design to manage the risks. Transportation Planning and Technology, 31, 1, 35-68.

de Neufville, R.; Belin, S. (2002). Airport passenger buildings: efficiency through shared use of facilities. Journal of Transportation Engineering, May/June.

de Neufville, R.; Cardin, M.-A. (2008). A Survey State-of-the-art Methodologies and a Framework for Identifying and Valuing Flexible Design Opportunities in Engineering Systems. Working Paper, Cambrigde, MA.

de Neufville, R.; Odoni, A. (2003). Airport Systems: Planning, Design and Management. The McGraw-Hill Companies, ISBN 0-07-138477-4.

de Neufville, R.; Scholtes, S. (2011). Flexibility in Engineering Design. Engineering Systems. The MIT Press, Cambridge, Massachusetts, EUA.

Eckart, J. (2012). Flexible urban Drainage Systems in New Land-use Areas. Doctoral Thesis, Department of Civil & Environmental Engineering, College of Engineering, University of South Florida.

EUROCONTROL, (2013). Challenges of Growth 2013 – Task 4: European Air Traffic in 2035. http://www.eurocontrol.int/sites/default/files/article/content/documents/official-documents/reports/201306-challenges-of-growth-2013-task-4.pdf (last accessed October 15th, 2014)

Gil, N.; Tether, B. (2011). Project risk management and design flexibility: analysing a case and conditions of complementarity. Research Policy, 40, 415-428.

IATA – International Air Transport Association. (2004). Airport Development Reference Manual. 9th Edition, Effective January, Montreal, Geneva, Ref. No. 9044-09, ISBN 92-9195-086-6.

Koste, L.; Malhorta, M. (1999). A Theoretical Framework for Analysing the Dimensions of Manufacturing Flexibility. Journal of Operations Management, 18, 75-93.

Kwakkel, J.H.; Walker, W.E.; Marchau, V.A. (2010). Assessing the efficacy of adaptive airport strategic planning: results from computational experiments. 12th WCTR Conference, July 11-15 Lisbon, Portugal.

Magalhães, L., Reis, V., Macário, R. (2013). Airport Flexibility: a First Glimpse on the External Factors. 13th WCTR Conference, Rio de Janeiro, Brazil, July.

Morlok, E.K.; Chang, D.J. (2004). Measuring capacity flexibility of a Transportation System. Transportation Research Part A: Policy and Pratice, 38 (6), pp. 405-420.

Nelson, K.; Nelson, H.; Ghods, M. (1997). Technology Flexibility: Conceptulization, Validation and Measurement. IEEE, Proceedings of the Thirtieth Annual International Conference.

RACE2050, (2014). RACE2050 - Comparing the assessments of European transport industry foresights. http://www.race2050.org/ (last accessed October 15th, 2014).

Saleh, J.; Hastings, D.; Newman, D. (2001). Extracting the Essence of Flexibility in System Design. Massachusetts Institute of Technology, Eneginnering Systems Division, Working Paper Series, ESD-WP-2001-04.

Schuckmann, S.; Gnatzy, T.; Darkow, I.; von der Gracht, H.; (2012). Analysis of factors influencing the development of transport infrastructure until the year 2030 – A Delphi based scenario study. Tecnhological Forecasting & Social Change, 79, 1373-1387.

Shuchi, S; Drogemuller, R; Kleinschmidt, T. (2012). Flexible Airport Terminal Design: Towards a Framework. Proceedings of the IIE Asian Conference 2012, Furama Riverfront Hotel, Singapore, 348-356.

Slack, N. (1983). Flexibility as a manufacturing objective. International Journal of Operations and Production Management, Vol. 3 No. 3, 5-13.

Slack, N. (1987). The flexibility of manufacturing systems. International Journal of Operations and Production Management 7 (4), 35-45.

Taneja, P.; Ligteringen, H.; Walker, W.E. (2012). Flexibility in Port Planning and Design. European Journal of Transport and Infrastructure Research, Issue 12(1), pp. 66-87.

Tersine, R.J.; Riggs, W.E.; (1976). The Delphi technique: a long-range planning tool, Bus. Horiz. 19, 51.

Wijnen, R.; Walker, W.; Kwakkel, J. (2008). Decision Support for Airport Strategic Planning. Transportation Planning and Technology, February, Vol. 31, No.1, pp.11-34.

Zhang, Q.; Vonderembse, M.; Lim, J.-S. (2003). Manufacturing Flexibility: Defining and Analysing Relationships among Competence, Capability, and Customer Satisfaction. Journal of Operations Management, 21, 173-191.