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# **Real options as a tool for managing uncertainty in project management**

The New Lisbon Airport

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*Education is a progressive discovery of our own ignorance*

Will Durant



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## **ABSTRACT**

Infrastructure networks are essential to support the world economic development. Governments worldwide, in both developed and developing economies, have dedicated significant amounts of the public budget to infrastructure development and refurbishment. The large sunk costs and the uncertainty surrounding these projects require new and sophisticated investments analysis techniques.

Simultaneously there has been a recent trend for incorporating flexibility in these projects, allowing a more progressive adaptation to changing market conditions, thus decreasing the overall risk affecting these investments. In this particular case, flexibility will be introduced through real options which allow the infrastructure (and service) to cope with future uncertainty.

The success of the low-cost carriers, due to the market deregulation and the Schengen Agreement is one of several trends that lead to the airline industry revolution which now requires a new approach for airports strategic planning.

Lisbon's Portela airport will soon achieve full capacity despite on-going expansion planned to withstand 21 million passengers per year in 2018. Furthermore, urban development in the surrounding areas has landlocked the airport. To receive the surplus traffic, to adequately fill the needs of low-cost carriers and to maintain the commitment in operating as an intercontinental hub a new airport is required.

This research intends to analyse the economic value of incorporating flexibility in airport design under a real options approach, which provides a framework able to bypass traditional valuation methods limitations.

The real options model was implemented to study the construction of the New Lisbon Airport, valuing flexibility through a phased investment option.

**KEYWORDS:** Real Options, Flexibility, Airport, Infrastructure, Phased Investment Option.



## RESUMO

A construção de infraestruturas é um pilar do desenvolvimento económico mundial. Governos de todo o mundo têm alocado uma quantidade significativa do orçamento público para a construção e requalificação de infraestruturas. Os elevados custos afundados e incerteza em torno destes projetos, requerem novas e sofisticadas técnicas para avaliar investimentos.

Recentemente surgiu a tendência de incorporar flexibilidade nesses projetos, permitindo uma adaptação progressiva às novas condições de mercado, diminuindo o risco que afecta esses investimentos. A flexibilidade será introduzida através de opções reais que permitem lidar com a incerteza futura.

O sucesso das companhias aéreas de baixo custo, devido à desregulamentação do mercado e ao Acordo de Schengen é um dos factores que impulsionou a revolução da indústria da aviação que necessita de uma nova abordagem de planeamento estratégico dos aeroportos.

O aeroporto da Portela atingirá em breve a capacidade máxima, cujos sucessivos aumentos de capacidade permitir-lhe-ão servir 21 milhões de passageiros por ano a partir de 2018. Para receber o tráfego excedente, responder adequadamente às necessidades das companhias aéreas de baixo custo, mantendo o compromisso em actuar como hub intercontinental, é necessária a construção de um novo aeroporto.

O objectivo desta pesquisa é analisar o valor económico de incorporar a flexibilidade no *design* de um aeroporto, adoptando a abordagem das opções reais, cuja estrutura permite contornar as limitações dos métodos tradicionais de avaliação.

O modelo de opções reais foi implementado para estudar a construção do Novo Aeroporto de Lisboa, qualificando-se a flexibilidade através da opção de investir de forma faseada.

**KEYWORDS:** Opções Reais, Flexibilidade, Aeroporto, Infraestrutura, Opção de investir de forma faseada.



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## **LIST OF ACRONYMS**

AASP - Adaptive Airport Strategic Planning  
AICM - Mexico City International Airport  
AMP - Airport Master Planning  
ANA - ANA Airports of Portugal, SA  
APM - Adaptive Policymaking  
ASP - Airport Strategic Planning  
BOPM - Binomial Option Pricing Model  
BSOPM - Black-Scholes Option Pricing Model  
CTA - Campo de Tiro de Alcochete  
DfT - United Kingdom Department for Transport (DfT)  
DSP - Dynamic Strategic Planning  
EASA - European Aviation Safety Agency  
EEC - European Economic Community  
FAA - United States Federal Aviation Administration  
FO - Financial Options  
FSA - Full Service airport  
FSC - Full Service carriers  
FSP - Flexible Strategic Planning  
HRO - Hybrid Real Options  
IATA - International Air Transport Association (IATA)  
ICAO - International Civil Aviation Authority  
LCA - Low-cost airport  
LCC - Low-cost carriers  
MCS - Monte Carlo simulation  
NLA - New Lisbon Airport  
NPV - Net Present Value  
PM - Project Management  
R&D - Research and Development  
RADT - Risk-Adjusted Decision Trees  
RO - Real Options  
SEA - Single European Act  
SP - Strategic Planning  
USA - United States of America



# INTRODUCTION

## 1.1 - Introduction to the problem

Project management (PM) has assumed, in the last decades, a key role inside every financial organization. The purpose of PM is to foresee or predict as many dangers and problems as possible and to plan, organize and control activities so that the project is completed as successfully as possible in spite of all the risks. The ever-present elements of risk and uncertainty mean that events and tasks can never be predicted with absolute accuracy throughout their lifetime [1].

Large infrastructure investments, like roads, airports, dams or hospitals, are long-term projects, with large sunk costs. Moreover, the context involving these projects is frequently highly uncertain, particularly, regarding demand, capital costs or even construction costs [2]. This uncertainty has been acknowledged by the academic literature, but only recently the matter has been dealt by academics [3]. The proposed alternative is to design flexible infrastructure projects.

The inadequate performance of infrastructure represents a huge social and economic challenge that must be addressed by governments and their partners. Without the necessary infrastructure and public services, economies cannot meet their full potential while severely harming human and economic development. Not investing in new infrastructure projects does not mean not to invest in the maintenance of existing infrastructure.

Bearing this, the questions that stand are: in a context of economic crisis, how to improve the performance of infrastructure and public services, without engaging in high investments? Are the current financing and managing models efficient enough or is there room for a new model? What is the tool that allows dealing with the innumerable uncertainties associated with this type of contracts reducing complexity and enabling them to adapt as necessary?

Despite its presence in fields such as biology and medical sciences, being defined as a characteristic of living organisms to adapt themselves to changing condition only in the recent decades the concept of flexibility became appealing to apply in areas like economic and management among others.

The rationale for incorporating flexibility in infrastructure projects is rather simple, unlike the empirical application which can be extremely complex. The principle is that the project should have the necessary flexibility to adapt to future changes, e. g. at the design stage it is necessary to incorporate

flexible options that would allow the infrastructure and/or the service, to be adapted to a certain change.

Emerging from the financial market, real options (RO) have their origins in the seminal work of Black and Scholes and also in Merton's research which provided the theoretical formulation to evaluate financial assets – options [4] [5]. RO are, nowadays, a growing valuation tool for infrastructure investments. Their growth in the last two decades meets the needs of new methods to evaluate projects value since Discounted Cash Flows (DCF) techniques do not allow capturing the inherent value of flexibility [6].

The need to plan taking into account future uncertainties, the shortage of financial resources by the public sector and the need for constant investment in infrastructure had their impact on Airport Strategic Planning (ASP).

Airport Master Planning (AMP) was for several decades the traditional approach followed to plan the construction of such infrastructure. In the last decades, events such as the liberalization of airspace, the emergence of low-cost carriers (LCC), the terrorist attack of 9/11 in the United States of America (USA) and the most recent economic crisis, helped expose the greatest weakness of this method – relying on forecasts to determine the future traffic evolution [7]. In order to fill this gap, new approaches arose in the beginning of the XXI century, being the most recent one the Adaptive Airport Strategic Planning (AASP), which incorporates flexibility in Airport Strategic Planning (ASP).

Urban development around the Portela's airport has limited its expansion capacity, a capacity that will be reached in 2018 (21 million passengers per year) [8]. Moreover, in order to receive the surplus traffic, to adequately reallocate and capture LCC traffic and to maintain the commitment in operating as an intercontinental hub a new airport is required. Since the 1960's that this issue has been approached although, now more than ever, a new airport infrastructure is needed to capture the increasing demand and to strengthen the position of Portela airport as an intercontinental hub.

The severe economic crisis that befell in Europe and particularly in Portugal, forced the privatization of ANA Airports of Portugal, SA (ANA) to the Vinci group. Therefore, it will be up to the Vinci group to, among many airports, manage the Portela airport, and eventually the New Lisbon airport (NLA) – case-study of this research.

Resorting to three different scenarios, it will be discussed and evaluated whether it is advantageous or not, to construct the new airport incorporating flexibility in the design and planning, over a 50 year period. RO approach was the chosen model to capture the value of flexibility within the investment in the NLA which will be quantified through a phased investment option.

## **1.2 - Valuation methodology**

The large sunk investments and the uncertainty surrounding these projects, require new and more sophisticated investment analysis techniques than DCF. Simultaneously there has been a recent trend for increasing flexibility in these projects, allowing a more progressive adaptation to changing market conditions, thus decreasing the overall risk affecting these investments. The flexibility is introduced through RO.

The research discussed in this thesis appraises the value of the phased investment option by comparing the construction of the NLA able to withstand 40 million passengers per year (inflexible scenario) against a modular construction of the NLA (flexible scenario) initially ready to receive 10 million passengers per year.

In order to capture the latent value of the NLA analytical tools, common to RO theory, were employed. It is worth highlighting the resource to the binomial lattice model to dynamically project the traffic evolution, the Net Present Value (NPV) to estimate how much the project is worth and the Monte Carlo simulation (MCS) to determine the fair value of the option, since it focuses on the expected NPV.

## **1.3 - Thesis goals**

The financial and economic crisis that took over Europe obliges governments to rethink the way public funds are spent. In this research it is intended to demonstrate how flexibility presents itself as a solution for a more efficient management of economic resources.

The core objective within this research is to assess the value of the underlying flexibility concerning the design and construction of the NLA. To quantify its value three different scenarios, based on ANA's concession contract, were studied and evaluated in order to estimate their different NPV as well as the value of the phased investment option. Data inputs for the model were largely based on data from Portela airport for Full Service Carriers (FSC) while inputs for the LCC required a broader data collection.

Other objectives implicit to this thesis concern: estimating when Portela reaches full capacity - the year in which the NLA should start operating – the advantages of RO theory when compared to other valuation techniques and, possibly, if the phased investment option is worthwhile.

## 1.4 - Thesis structure

After this brief introduction this document is organized as follows:

➤ In Chapter 2 - *Airport Evolution* - the recent changes in the air industry are reviewed emphasizing the more relevant ones. In this chapter an overview regarding the modern airport industry is provided while the countless uncertainties that airport planners and managers face nowadays, due to these new trends, are highlighted. Subsequently, flexibility in design is presented as the ultimate solution to face those uncertainties. Following, the evolution of ASP approaches, from traditional AMP to the latest and flexible Adaptive Airport Strategic Planning (AASP), is addressed. This chapter ends with academic examples of flexibility applied in airports systems.

➤ Chapter 3 - *Real Options* - introduces the topic of options. The literature review addresses their evolution from financial markets, its later application to real assets, their taxonomy and the valuation methods used are also covered in this chapter.

➤ The 4<sup>th</sup> Chapter - *The New Lisbon Airport* - begins with an introduction to the company that managed the majority of Portuguese airports (including Portela) – ANA, Aeroportos SA being analysed in detail the current Lisbon airport. Reference is made to previous studies on the NLA followed by the case study introduction. In the last part of the chapter the scenarios that will be studied are thoroughly described.

➤ Chapter 5 - *The Real Options Model* - the RO model developed is explained and applied to the case study. The main results obtained, the sensitivity analysis performed and the MCS values are discussed.

➤ The 6<sup>th</sup> and final Chapter - *Conclusions* - synthesizes the work done and the main conclusions regarding the preceding chapters, primarily focusing on the results obtained with the implementation of the RO model. Moreover, some outstanding issues due to restriction in information availability are also addressed.

# AIRPORT EVOLUTION

## 2.1 - Airport infrastructure

Globalization brought many benefits. The need to explore and travel started in Portugal in the 15<sup>th</sup> century with the *Descobrimentos* era. As technology evolved, new ways of travelling – faster, safer and economically cheaper – emerged to fulfil man's needs. Drivers such as globalization, speed, agility and tourism contributed to the development of the 5<sup>th</sup> wave of urban development – the airport infrastructure [9].

Airport infrastructures have as main basic functions being the interface between the aerial and land transportation means as well as conversion of continuous flows of passengers and goods into aggregated air flows [10]. To perform these tasks airports provide airline and passengers a set of activities distributed between airport terminal (*landside* and *airside*) and air traffic control. The *landside* is characterized as being *work intensive* while, on the other hand, the *airside* is characterized as *specialized know-how*. The technical services to guarantee aircraft's security and to support their movements are given by the air traffic control. Figure 1 summarizes the main components an airport terminal.

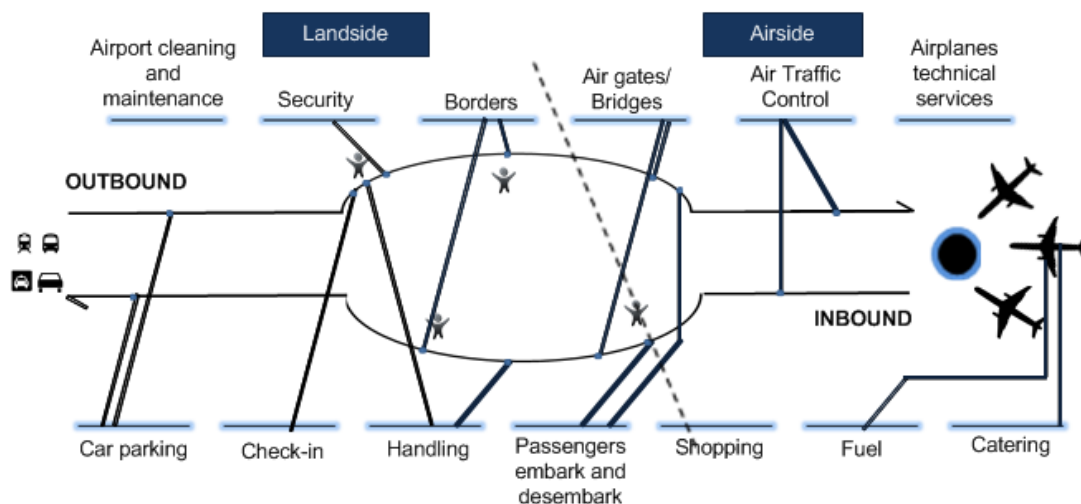


Figure 1 - Airport terminal: airside and landside.

Source: adapted from [10]

The services that are under airport authorities' are displayed on the top half of Figure 1 whereas the services that can be outsourced are shown on the bottom half of the image. The airports are no longer merely a boarding/unboarding infrastructure but a place for countless business opportunities to arise.

## 2.2 - The Airline Deregulation Act

### 2.2.1 - Market deregulation

The Aviation sector as is known nowadays started to take form after the 2<sup>nd</sup> World War. Formerly airport owners and airlines operated in a highly regulated and predictable environment. This oligopolistic market allowed making long-term forecasts believing that these conditions would remain unchanged.

Domestic aviation in European countries was regulated through a bilateral system of agreements evolving from the Chicago Convention of 1944 [11]. European airlines operated under a strict system of regulation composed by: single airline destination, tight capacity agreements on market access and IATA-fixed fares [12]. The desire for competition (whose final outcome would be the decrease in prices) from the public, motivated the economic deregulation of the airlines [13].

Being so, the first deregulation in air transport occurred in the USA in 1978, when President Jimmy Carter signed the Airline Deregulation Act, restricting the authority of the Civil Aeronautics Board to regulate commercial aviation for the first time since 1938 [14]. This act removed government control over fares, allowing new market entries. Suddenly, the oligopolistic market disappeared giving place to new opportunities either in routes, prices, frequency of flights or aircraft types (Table 1)

**Table 1 - Implication of the market deregulation on the oligopolistic market.**

Choices	Before deregulation	After deregulation	Implications of deregulation
Routes	Strictly controlled	Freedom to change	Loss of secure tenure
Prices	Set by formula	Freedom to change	Price wars
Frequency of flights	Controlled	Freedom to set schedules	Capacity wars
Aircraft types	Often controlled	Freedom to choose	Capacity wars

Source: [15]

The impact upon Europe was immediate. Discount fares emerged new carriers entered the market and many services started being offered [12].

### 2.2.2 - The European response to the airline deregulation act

Due to the regulatory framework in vigour in Europe, the European market was less competitive than the American, even before the market deregulation [12]. In 1978 a British study concluded that the productivity of staff members working in the USA airlines was almost 50% higher than the one from the staff members operating for European airlines [16].

To face the impact of US market deregulation, the European Communities Commission developed a 3 package plan to liberalize the European air transport market - 1988, 1990 and 1993 [17]. Despite being more gradual than its American counterpart, this process was very similar in its content [18].

Safety standards and air traffic management were developed at a national level until, in 1992, the European Union tried their integration after the Single European market came into effect [19]. The European airspace needed to be reformed. Bearing this in mind the European Aviation Safety Agency (EASA) was created in 2002, whose main objectives were related to increasing the levels of air travelling safety [20]. This was the keystone to the Single European Sky – a new regulatory system for a single European market in air transport which came into effect in April 2004 [21].

In April 2007 and after several years of negotiation, a first stage transport agreement was signed between the EU and US [12] <sup>1</sup>. The ability to set prices accordingly to the market, to operate flights to the USA from every European airport without restrictions on the number of aircrafts, routes or number of flights and the possibility of concluding cooperation agreements were the main benefits brought to airlines by this new agreement.

Finally, in 2008, the air space between the 27 countries of the European Union (EU) and the USA became deregulated implying no restriction on prices, routes or number of flights [22]. Air travelling is nowadays a more democratic mean of transportation than before market deregulation.

## **2.3 - European Union: together we stand, divided we fall**

### **2.3.1 - Single European Act - The road to European Union**

The creation of the European Economic Community (EEC), with the Treaty of Rome in 1957 brought several benefits to its members [23]. The treaty proposed the creation of a common market of goods, workers, services and capital benefiting the EEC's member states with a single purpose – a global Europe. The concept of globalization gained increased momentum with successive amendments to the Treaty of Rome, being the most recent the Lisbon Treaty [24]. The following figure illustrates the evolution of the European Union.

---

<sup>1</sup> Although the agreement was reached on the 2<sup>nd</sup> March 2007 it only entered into force on the summer of 2008.

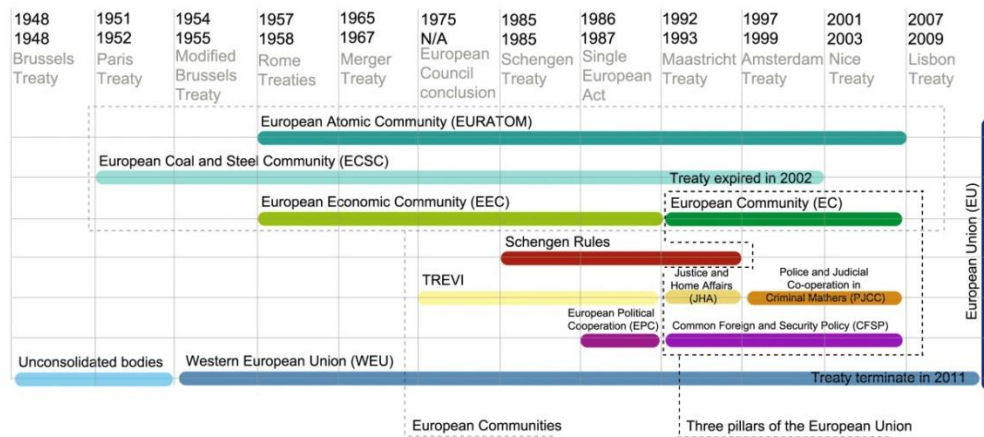


Figure 2 - Treaties and Policies evolution in Europe.

Sources: Several

The echo from the lack of freedom of movement between member countries inside the European community began generating discontent among members of the European Community in the 1980's [12]. The time called for a more collaborative legislative process<sup>2</sup>. The first amendment of the foundational treaties of the European Communities (Treaty of Paris in 1951 and the Treaties of Rome in 1957) arises then on December 1<sup>st</sup> 1985 as a political agreement on the European Council held in Luxemburg. The Single European Act (SEA) is first signed by 9 members on the 17th of February 1986 and finally on the 27<sup>th</sup> of February by the remaining 3 countries [25]<sup>3</sup>.

The SEA's main goals were: completing the internal market, adding momentum to the European integration, ensuring fair competition among European companies and expand the community power primarily in the fields of Research and Development (R&D), environment and foreign policy.

As summarized by the former President of the EEC, Jacques Delors: 'The Single Act means, in a few words, the commitment of implementing simultaneously the great market without frontiers' [26]<sup>4</sup>. Besides promoting the economic and monetary union as a core element in the integration process, Jacques Delors also tried to balance the advancements on free trade that benefited managers directly. The Stock Exchange crash in 1987 as well as the problems of the European Monetary System in 1992 led the European political leaders to take a decisive step towards the European Union. The Treaty of the European Union was approved in Maastricht in 1991 [27]<sup>5</sup>. It was then signed and came into force on the 7th of February, 1992.

<sup>2</sup> This process would be called Cooperation procedure.

<sup>3</sup> The timeline of this act coincides with the ascension of two more member states of the EEC – Portugal and Spain (1986).

<sup>4</sup> Unlike Jacques Delors, Margaret Thatcher was against the concentration of power at a European conglomerate.

<sup>5</sup> This is also known as the Treaty of Maastricht.

## 2.3.2 - The Schengen agreement

On June 14 1985, near the town of Schengen in Luxembourg, the Schengen Agreement was signed [28]. This agreement allowed transiting from one country to another, within the Schengen area, without border controls. The Schengen Convention, held in 1990, proposed the abolition of internal border controls as well as a common visa policy, supplementing. The treaty led to the creation of the Europe's borderless Schengen Area in 1995.

The Treaty of Amsterdam, signed on 2 October 1997, incorporated the Schengen treaty and its rules into the European Union Law [29]<sup>6</sup>. Nowadays the Schengen Area consists of 26 European countries as illustrated in the following figure<sup>7</sup>.



Figure 3 - Schengen area.

Source: [30]

## 2.4 - New trends

### 2.4.1 - Hub-and-spoke infrastructure

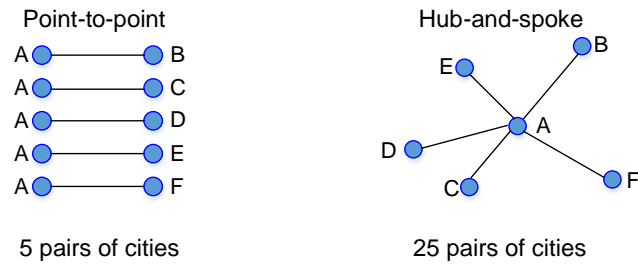
Airports' infrastructure, legislation and policy were not the only visible changes in the airline industry. The traditional point-to-point operation (connection between a pair of cities) was replaced by hub-and-spoke operations (central hub owned by an airline which is the main destination of its flights)<sup>8</sup>. The main advantage of hub-and-spoke when compared to point-to-point is the connection in banks [31]<sup>9</sup>. These networks provide the maximum number of city-pair connections at the maximum frequency [32]. Figure 4 illustrates these two networks operation methods.

<sup>6</sup> The treaty entered into force on May 1st 1999.

<sup>7</sup> In 1985 only 5 of the 10 member states signed the agreement – Belgium, France, Germany, Luxembourg and Netherlands.

<sup>8</sup> FSC have clearly adopted the hub-and-spoke operations unlike most of the LCC.

<sup>9</sup> A bank is the process in which a group of aircrafts land, their passengers disembark and cross the terminal for the connecting flight. Following, the passengers embark and the aircraft takes off.



**Figure 4 - Point-to-point vs hub-and-spoke network**

Delta Company, based in Atlanta, was the first company to replace the typical point-to-point service to a hub-and-spoke structure [33]. This new structure allowed considerable increase in service for two different types of travellers: the ones living in the hub-airport city (gained access to an increased number of flights and destinations) and to residents of small cities on the spokes who, although losing some point to point service, gained access to many more destinations [34]. London's Heathrow airport and Paris' Charles de Gaulle, both with over 60 million passengers per year, are examples of large hub-and-spoke infrastructures that appeared recently in Europe [35].

#### 2.4.2 - Low-cost carriers - 1 new product, countless uncertainties

Liberalization had as most important outcome the appearance of LCC [36] [37]<sup>10</sup>. The concept of LCC was firstly implemented in the USA, in 1949, by Southwest airlines [38]. Several decades later, the model began to be copied on a global scale. In 1991, 6 years after its foundation and under a new management team, Ryanair became the first LCC in Europe and four years later Easyjet, the 2<sup>nd</sup> LCC operating in Europe, was founded [39] [40]<sup>11</sup>. Nowadays, these are the two LCC with greater market share in Europe, although operating under two completely different types of business models. Ryanair focuses on leisure markets without direct competition, serving secondary airports with low frequency, while Easyjet focuses on existing and new markets dealing with competition and serving primary high costs airports [41]. Despite their differences there is little evidence suggesting passengers will pay a price premium for additional service features [42]. Although Gillen and Lall [43] discussed the variety of form of LCC, their primary definition is based in the cost of production, i.e. seat per mile [44]. Despite their differences, these carriers share the cult of cost reduction [36].

To attain such reductions, they operate in order to obtain three different groups of savings: service, operational and overhead [41]. Thus being, their business model offers the most basic packs which can turn out to be only the seat the passenger will use to travel. Operating in a point-to-point basis is another way to increase LCC savings while providing customers with less time consuming trips [45]. Using routes with high density traffic and travelling between cities that require short time travels is also a key component to the success of the LCC business model [41].

<sup>10</sup> The collapse of the Eastern Block and the subsequent reduced needs by the military services also had an important contribution in the LCC ascension.

<sup>11</sup> Ryanair evolved from a Legacy carrier into a copy of American Southwest Airlines.

The use of secondary airports or reconverted military fields by the LCC caused major airports to lose their monopoly on air traffic. Thus being, competition with airports near the city centre main airport is a new uncertainty that affects ASP. Primary airports, located near the city centres are, now more than ever, under a huge treat as evidence shows that passengers prefer to have lower air fares even if it takes longer to reach the city centre [46]. The effective use of resources alongside LCC's focus on cost reduction led to higher growth rates when compared with the average of the sector [47]. Hence their market share increased alongside with their influence on the aviation industry [48]. Despite the economic crisis in Europe, the increase in oil prices and the stagnant growth of the majority of Legacy Carriers, both Ryanair (greatest LCC in Europe) and Easyjet increased the number of passengers, from 2011 to 2012, by 5 and 7,16% respectively [49] [50]. Despite an increase in turnover of 367 million euros in, Ryanair reached an historical record in 2012 with revenue of 4,325 million euros, growing 19% over the previous year.

The increase in the number of uncertainties that came alongside with the LCC growth made airport designing an ever harder task for project managers to deal with. The main differences in airport infrastructure requirements between LCC and Legacy Carriers are displayed in the following table.

**Table 2 - Differences in airport infrastructure requirements between FSC and LCC.**

		<b>FSC</b>	<b>LCC</b>
Access	<i>Location</i>	Convenient location is of major importance, specifically for non-economy passengers	Location of secondary importance. Good road and rail links preferable although not essential
	<i>Ticketing area</i>	Small. Focus on internet sales	Reflect corporate image and presence
Terminal	<i>Check-in</i>	Fast. Quality is not a primary concern	Convenience and profile
	<i>Services</i>	Secondary importance	Important to meet passengers purchasing needs
	<i>Facilities</i>	Not important	Image of major international hub with good facilities is preferable
	<i>Technology</i>	Low (air steps)	High (air bridges)
	<i>Air-bridge</i>	Power in and out of gate (not required)	Essential to product image
Gate	<i>Facilities</i>	Economy lounge only	Business and first class lounges required besides economy space
	<i>Turn-around times</i>	Fast; route incoming and outgoing passengers preferable.	Long to route passengers in appropriate manner
	<i>Catering</i>	Minimal facilities required	Facilities for preparation of in-flight food essential as forms part of package
General	<i>Cleanliness</i>	Required less frequently	Essential part of the package
	<i>Standby aircraft</i>	No parking during daytime	Requires parking
	<i>Aircraft baggage</i>	Efficient loading and removal	Efficient delivery of arriving baggage to customer is a priority

Source: adapted from [51]

The need to plan and build for a new type of carriers is now another uncertainty to be taken into account when planning and constructing an airport infrastructure.

### 2.4.3 - Midfield terminals

Airports served no longer the single purpose of transporting passengers directly as they recently started to be used also as transfer points. These changes required new infrastructures, with different characteristics able to deal with this new type of passenger. Airports required midfield passenger buildings (or midfield terminals) [52].

### 2.4.4 - Strategic alliances

Strategic alliances, which are characterized by joint, dedicated marketing entities for network-wide cooperation, emerged in the 1980's and keep gaining momentum since the 1990's [53] [54].

These arrangements aim at obtaining very specific goals such as: reducing transaction costs, risk sharing, integrating networks, while mutually adding value as has been covered in theoretical literature [55] [56] [57] [58].

Flag carriers resorted to these strategic alliances to face the threat of the LCC. The emergence of hub-and-spoke networks boosted their growth [59]. This was a way to extend their operational network without operating additional flights since, by conveying all passengers into the hub, these networks generate huge traffic densities on the spoke routes, yielding lower cost per passenger [60] [61] [62] [63].

### 2.4.5 - Multi-airport systems

De Neufville and Odoni [13] defined Multi-Airport-Systems (MAS) as a set of significant airports that serve commercial transport in a metropolitan region, disregarding ownership or political control of the individual airports. The MAS definition is based upon 4 pillars:

- To be considered a MAS two or more airports must coexist inside the same metropolitan region instead of in the same city (as one region may include several cities);
- Since these systems are market-focused, the ownership of the airports is irrelevant;
- Military basis and airports not traffic-dedicated are left out of this definition; and
- Airports that serve more than a million passengers a year (or 100.000 tons in freight) are the main focus<sup>12</sup>.

A major feature of this system concerns the amount of traffic that originates and ends in these metropolitan areas. MAS are spread across several world-class cities, such as London, Paris or New York, due to the ability to attract and generate huge amounts of traffic, as this is a crucial requirement [64]. Thus, to be considered a MAS, it is necessary that at least 14 million passengers have as origin or destination one metropolitan area being this value calculated by equation 1 [13]:

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<sup>12</sup> This requirement is not mandatory as can be seen in section 2.4.5.3 with London/London City airport.

$$\text{Originating traffic} = \frac{1}{2} * (\text{Total passengers} - \text{Transfer passengers}) \quad (1)$$

The continuous increase in air traffic is the main reason for the appearance of these systems. MAS allow the decentralization of passenger traffic and air cargo from major airports to suburban airports in order to balance capacity utilization and maintaining the service levels at the primary airports [65].

The conventional structure of a MAS is characterized by a main international airport that serves as an established hub for major international (full-service) carriers and one (or more) secondary airports serving the domestic market [64]. In Europe, these secondary airports are mostly used by the LCC who take advantage of the reduced costs, making a better use of their point-to-point network. Regarding traffic, typically the major airport supports most of it whereas one or more secondary airports support between 10 and 50% of the primary airport's traffic [13].

#### 2.4.5.1 - From 'catchment area' to 'metropolitan area'

The worldwide changes in urban and regional structure are the major reason for the change into a more functional, geographic definition of a metropolitan airport system [52]. In an increasingly globalized world, where the population grows unmeasured and the connections between cities are made by means of transport that grows faster every day, it no longer makes sense to think in a city individually. Nowadays, it is not necessary to live in the area surrounding an airport to have quick access to it. Bearing this in mind, it is wiser to think in a metropolitan area - area accessible to passengers from the airport – rather than in a catchment area as the first one becomes more important than the city itself [13] [46].

#### 2.4.5.2 – Multi-airport system and low-cost-carriers: growing alongside

As discussed in section 2.4.2 the emergence of the LCC has increased the number of uncertainties present in the world of air transport. The operational differences and concerns about the costs forced the industry to adapt to the needs of these new players. The demand for secondary airports with less traffic congestion and reduced costs, while still providing access to key population centres, boosted the appearance and growth of MAS [46]. Thus being, each phenomenon seems to fuel the growth of the other. Bonnefoy and Hansman are in accordance with this idea as they consider the entry of LCC as the key stimulus to the appearance of secondary airports which form MAS [66].

MAS give passengers a greater choice regarding the number of airports while allowing differentiation between airports particularly in what concerns niche markets' development. This differentiation enables competition and cooperation among each other, thus enabling the link between

MAS and LCC enabled the development of new market dynamics within air transport [46]<sup>13</sup>. The emergence of this new system adds new uncertainties that need to be taken into account when planning and building an airport. Table 3 displays these uncertainties.

**Table 3 - MAS' new uncertainties.**

<i>Where will the traffic develop?</i>
<b>[1] Secondary airports create increased competition for traffic.</b>
<i>What will be the shape of the airport industry?</i>
<b>[1] Competing airports yield increased differentiation.</b>
<b>[2] Some airports are moving toward the “aerotropolis” idea, others are better serving LCC.</b>
<i>Which customers should airports cater to?</i>
<b>[1] Increased airport differentiation allows for passenger segmentation.</b>
<b>[2] Some large airports are attempting to integrate non-traveling customers into their revenue base by adding services.</b>

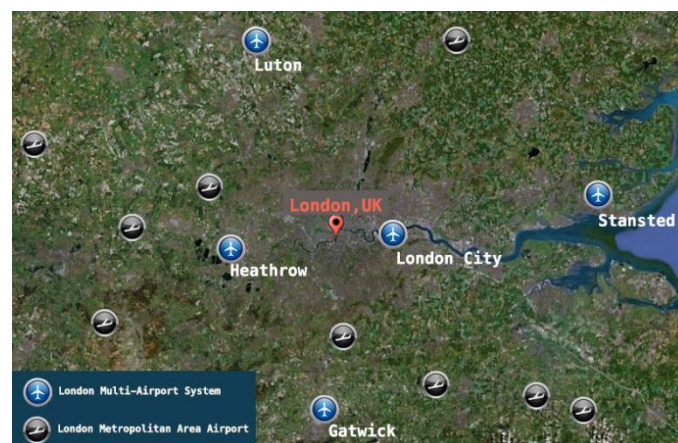
Source: adapted from [46]

#### 2.4.5.3 - The London example

London MAS is composed by 5 airports [45] [67]:

- Heathrow, the largest airport;
- Gatwick, a former British Caledonian Airlines hub of operation;
- Stansted, owned by BAA alongside with Heathrow and Gatwick;
- Luton, whose main customers are vacation travellers; and
- London City, an airport near London financial center dedicated to business travelers.

These five airports differ either by type of customer or by different services each one provides in order to meet their customers' needs. The image below illustrates the airports around London metropolitan area, highlighting the ones that form the London MAS and showing that, despite the several airports in London metropolitan area, only five of them are part of the London MAS.



**Figure 5 - London MAS.**

Source: 68

<sup>13</sup> Market dynamics provide the basic explanation of the level and distribution of traffic among airports in a MAS. The competitive market forces define the underlying structure of the outcomes. The dynamics of the competition between the markets makes the longer-term outcomes uncertain. A market may be organized around individual airlines, destinations, types of services or fare levels.

London/Heathrow is the main airport in the London MAS, being the busiest airport in Europe in terms of passenger traffic and the third one concerning traffic movements (Paris-Charles de Gaulle lead the list) [69]<sup>14</sup>.

London/Gatwick has a constant traffic of around 20 million passengers per year. Since market deregulation and British Airways privatization this airport lost the guaranteed traffic rights (which conferred it around one third of London's total traffic) serving now around one quarter of London's total traffic [70].

London/Stansted operates under a controversial situation. This airport does not justify the investment made (a large modern terminal and a dedicated railroad link to the city centre) and depends upon the political willingness of establishing this infrastructure as well as the insistence that the MAS should support it [52].

London/Luton is a specialized airport serving mostly vacation travellers and low cost operators. Since the airport was developed in a previously existing Air Force base (with runway and taxiways already built) it came at considerably almost no cost [71].

Finally, London/London City is a small airport for customers who want to access London financial center faster.

Each of these five airports plays a different role in the London MAS aiming at different niche markets and possessing their specific market dynamics.

#### 2.4.6 - Airport cities: coping with new needs

The market deregulation and the Schengen agreement increased the demand in such a way that the number of people using the world's largest airports started to be superior to the population of large cities. Accordingly, airports were evolving to projects similar to shopping centres [10]. The non-aeronautical revenues were another new trend that governments and private airport owners wished to start on capitalizing.

Conway (1980) was the first author suggesting the airport city concept [72]. In his point of view, these cities were composed by office and industrial parks, cargo and distribution facilities as well as attractions and travel facilities. Only in the 21<sup>st</sup> century this concept was seriously considered and promoted in both academic and commercial literature [73] [74] [75] [76] [77] [78].

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<sup>14</sup> The designation used in MAS follows: Metropolitan Area/Airport Name

Airport owners were not the only ones taking advantage of the airport cities concept. The importance of mobility nowadays is such that several companies explored the opportunity to invest in office buildings and facilities close to these cities, in their Aerotropolis [79].

#### 2.4.7 - Political orientation

Given the global dimension of the project under study – an airport infrastructure - changes in political orientations is an exogenous uncertainty to add to many other endogenous uncertainties this project already faces. Thus being, this project is sensitive to both idiosyncratic changes in national priorities as well as to public pressures [80]. Gaining a competitive advantage is a major concern of airport owners and project managers when planning such an infrastructure. These strategies must be developed resorting to flexibility as the ultimate tool [81].

### 2.5 - Flexibility in airport design: the core solution

A different approach than traditional AMP is required to deal with the several uncertainties that have arisen in recent decades<sup>15</sup>. As result of market deregulation it is now crucial to evolve and plan in order to cope with future uncertainties. Bearing this, a new ASP approach is needed.

Previously AMP was seen as the right methodology for the strategic planning (SP) of an airport infrastructure. Taking into account the changes in the airline industry, addressed in sections 2.2, 2.3 and 2.4, this methodology became obsolete. There was a need for a new methodology able to use flexibility and incorporate it in the design phase. Therefore, RO approach is the methodology that can fully explore flexibilities' features. Besides all the main benefits of RO which will be presented in Chapter 3, this methodology adds the possibility of phased investment programming, which allows developing an expansion plan that, in a scenario of uncertainty, mitigates the costs of an unfavourable evolution of passenger traffic. De Neufville's five-step methodology will be implemented to estimate the distribution of future possibilities. The five steps are [82]:

1. Identify the important factors: prioritize the different variables to reduce their number to the ones that are mission-critical for the future;
2. Analyse historical trends: establish the historical trends of the key performance drivers while using as much hard data as possible to challenge unfounded assumptions that might otherwise distort the analysis;
3. Identify trend-breakers: analyse carefully historical data. Involve major stakeholders in scenario planning. Develop a realistic set of future scenarios so that the design can anticipate these eventualities. Judgment based rather than evidence;
4. Establish forecast (in)accuracy: compare previous forecasts with what actually happened. Analyse past forecast errors;

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<sup>15</sup> AMP approach is discussed in detail in section 2.6.

5. **Build a Dynamic Model:** put the first 4 steps together and build a model to generate many different possible evolutions of the system environment. Engineers and system architects should optimize their designs against the fluid and unpredictable futures that these models produce.

To capture the latent project value that lies within uncertainties, companies need to behave proactively, they need not only to react to the market but act towards it. It is obvious that pre-project planning is important but it cannot cope with changes that will happen throughout its lifetime [83]. This is the main reason why companies should always leave an open door so as to maximize their benefits (buying specific material when it is cheaper, building when the weather is favourable, among others). This explains why some of the managerial choices cannot or should not be taken during pre-project planning – to increase project value.

Not to include flexibility in the construction of an airport has been proven rather harmful. Terminal 2 of Frankfurt Airport is underutilized due to its inability to adapt to the hubbing needs of Lufthansa and Star Alliance and the Bangkok airport had an increase in capitalized costs of at least 25% since operations had to be delayed for two years due to the inability to adapt to LCC and other industry developments [84]. These examples, which represent saves of millions of euros, highlight the airport's need to be prepared to face future uncertainties as well as to rapidly adapt to airlines' needs.

Flexibility is more valuable the higher the number of uncertainties associated with the project (contingency plans and insurance does not make sense if the existence of uncertainty is not recognized). Since its behaviour resembles a switch, flexibility can be seen as an attractive asset [80]. Due to its asymmetric property, incorporating flexibility in a project brings huge benefits at a very low price when compared with the potential gains. The resemblance to a switch can be explained as follows: not using flexibility at a given time (switch is turned off) its value is 0. On the other hand, when it is used (switch is turned on) and as soon as the system adapts to the new circumstances it can take on substantial value. Therefore, the only RO exist if the design and implementation of the project are strategically set, accommodating for different scenarios of changes in demand and adapting to changing business requirements [10].

## 2.6 - Airport master planning

For several decades, AMP has been the dominant approach for long-term development of an airport infrastructure [13]. According to International Civil Aviation Authority (ICAO) [85] AMP is a formalized, structured planning process which results in a Master Plan that 'presents the planner's conception of the ultimate development of a specific airport'. Thus being, AMP focuses on plans development rather on the decision-making process. Its adoption as an airport strategy planning approach was influenced by the International Air Transport Association (IATA) manuals, books by

leading scholars and by the Federal Aviation Administration (FAA) in the USA [13] [86] [87]. Although master plans differ by nation, several similarities can be identified [46]<sup>16</sup>.

### 2.6.1 - Master plan process

A Master Plan describes the strategy of an airport operator without specifying the operational and concepts managerial issues. A Master Plan is generally developed for a horizon of around 20 years and follows a linear process [13] [87]:

- Analyse existing conditions;
- Make an aviation demand forecast;
- Determine facility requirements needed to accommodate this forecasted demand;
- Develop and evaluate several alternatives to meet these facility requirements;
- Develop the preferred alternative into a detailed Master Plan.

### 2.6.2 - Airport master plan's flaws

The demand forecast in the aviation industry is itself a huge source of uncertainty. AMP deals with this uncertainty in an inadequate way. First of all, AMP is designed based on a single forecast which underestimates the possibility of different future scenarios [7]. Secondly, accounting only for traffic demand as the only uncertainty is a blunder. Several other uncertainties such as those described in section 2.4 must be considered in order to obtain a more accurate traffic prevision. Finally, the plan is implemented without considering the possibility that conditions may change in the future. AMP's goal is to provide a blueprint that will determine the future development of the airport [7] [88] [89]. Due to these characteristics, AMP has a static nature with very little leeway to adapt to other conditions than those/the ones forecasted.

### 2.6.3 - Room for new approaches

The market deregulation opened doors to a new paradigm for designing and implementing airport infrastructure. Since forecasts are inaccurate and the future of airline industry is full of uncertainties a new design, able to deal with uncertainties, was needed. Traditional AMP, which used to design for a single set of requirements, was no longer seen as a reliable instrument to predict traffic evolution [90].

The assumptions that forecasts were reliable caused the loss of huge revenues to airports such as Kansas City, Amsterdam Airport Schiphol and Montréal Mirabel Airport. Kansas City airport lost one third of traffic when Trans World Airlines moved its headquarters to St. Louis due to the inefficient passenger buildings [52]. A plan with a time horizon of 20 years was accepted in 1995 for

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<sup>16</sup> These similarities were found following a review of planning literature made by the: ICAO, IATA, United Kingdom Department for Transport (DfT) and United States FAA.

the development of Amsterdam Airport Schiphol. After 4 years the plan was already obsolete due to inability to adapt to the growth in traffic demand [91]. In 1975 Montréal Mirabel Airport was built regarding a forecasted 40 million passengers by 2025. The failure to attract enough passengers compelled it to close for passenger traffic in 2004 [92].

The numerous changes that occurred in recent decades in the aviation industry have highlighted the need for new ASP approaches. With the number of uncertainties constantly increasing, it is necessary to plan resorting to flexibility instead of planning considering forecasts. There is now room for new approaches since traditional AMP has become obsolete for long-term planning.

## 2.7 - Adaptive policies

In order to promote continuous learning and adaptation in response to experience over time, Dewey [93] proposed to treat policies as experiments. Adaptive policies are 'designed from the outset to test clearly formulated hypotheses about the behaviour of an ecosystem being changed by human use' [94]. Adaptive policies emerged as an alternative to the traditional AMP in the beginning of the 20<sup>th</sup> century. These policies preserve flexibility by combining time urgent actions with those that make important commitments to shape the future. Three alternatives emerged to AMP. These are de Neufville's Dynamic Strategic Planning (DSP), Adaptive Policymaking (APM), and Flexible Strategic Planning (FSP) [13] [52] [91] [95] [96] [97] [98].

## 2.8 - Adaptive approaches

### 2.8.1 - Dynamic strategic planning

#### 2.8.1.1 - Dynamic strategic planning overview

DSP is an approach, particularly for infrastructure, that can be easily adjusted over time to the actual situation and conditions [7]. DSP may be seen as traditional master planning adapted to the 21<sup>st</sup> century aviation industry's needs. This approach is *strategic* as it takes the long-term view and *dynamic* as it recognizes and anticipates the need to adjust plans in order to meet the actual requirements [13]. DSP recognizes uncertainty leading to a flexible development strategy, thus positioning the airport to minimize risks and take advantage of opportunities [96].

The resulting DSP defines a flexible development over several stages; committing only to a first stage and then proposing different developments in the forthcoming stages. The idea of planning accordingly to forecasted is replaced in this approach by anticipating the range of possible futures. Thus being, DSP augments traditional AMP [97]. This approach encourages planners to think strategically, like chess players. Considering this, planners should [13]:

- Think many moves ahead;
- Choose an immediate development or move that positions airports to respond well to whatever develops next;
- Rethink issues after they see what happens in the next phase; and
- Adjust their subsequent developments or moves correspondingly.

Accordingly with this approach, plans should build in flexibility to deal effectively with a range of possible different futures. In DSP, flexibility is created through RO [96]<sup>17</sup>.

#### 2.8.1.2 - Dynamic strategic planning process

There is no clear prescribed process for performing DSP, although there are seven distinct categories consisting of methods and activities that together result in a dynamic strategic plan [7]. These are [96]:

- I. Modelling: this activity should result in one or more models of the technical system and its performance;
- II. Optimization: this activity should result in an overview of different cost-effective means for achieving specified levels of results;
- III. Estimation of probabilities: since the performance of a system in the future cannot be forecast, it is necessary to estimate the range of values for key system parameters and the likely probability distributions for these parameters;
- IV. Decision Analysis (DA): by combining the results from the previous three activities, a DA for the set of choices can be carried out;
- V. Sensitivity Analysis: this activity should make sure that the outcome of the DA is robust with regard to changes in parameter values;
- VI. Evaluation of RO: this activity should focus on identifying cost-effective RO that increase the flexibility of the plan. These can then be inserted into the DA;
- VII. Analysis of implicit negotiation: the implementation of a plan is to a large extent dependent on the support of relevant stakeholders. This activity aims at analysing the stakeholders and their possible behaviour. The results are to be taken into account when thinking about the implementation of the plan that is developed through activities 1-6.

#### 2.8.1.3 - Dynamic strategic planning first application

Literature in this new approach started emerging in 1991, when de Neufville applied SP in the second Sidney airport study [95]. The resort to SP resulted from its capability to recognize uncertainty in long-term forecasts (this flexible approach sharply contrasts with the conventional AMP)<sup>18</sup>. DSP accepts risk as an inescapable reality and deals with this issue adopting a strategy (flexible approach

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<sup>17</sup> Real options will be discussed in detail in Chapter 3.

<sup>18</sup> In 1991 de Neufville (1991) used the nomenclature SP instead of DSP.

to deal with contingencies as they occur) and investing in insurance (protection against bad prospects). The first phase of action is the focus of this strategy, leaving the other stages to be defined whenever best suited. De Neufville defined the three core elements of SP as [95]:

1. Recognition of risk as the reality - deals with a range of possible futures instead of a single forecast;
2. Adoption of a strategy - flexible approach to better respond in case future events are different than those expected; and
3. Buying “insurance” - investing in projects which may only be needed in some relevant situations.

The alternatives presented in the study were: the selection of a site for the 2<sup>nd</sup> airport or taking no action. The author compared them in terms of performance over the range of possible futures and concluded that the adequate strategy passed by securing a site first of all - buying insurance<sup>19</sup> - and later on deciding on the actions concerning future events. Following the study’s planning, the Badgery’s Creek site was secured, anticipating future needs and allowing adding capacity slowly so as to permit slow development of its air transport – incorporating flexibility. This thesis also addressed a study concerning the construction of a 3<sup>rd</sup> runway. In this case the relevant variable was the disparity between level of traffic and the capability to serve it decently, in other words, the *capacity gap*. Building the 3<sup>rd</sup> runway in the existing airport or in the Sidney’s 2<sup>nd</sup> airport (not built at that time) were the study’s alternatives. The 2<sup>nd</sup> one was discarded both by the study team and airline companies since it was seen as an economic non-starter and airline companies did not want to move their facilities to a 2<sup>nd</sup> Sydney airport in the near future. From the airlines perspective it was commercially premature [99]. Building of the 3<sup>rd</sup> runway makes sense as part of a long-term strategy building. Moreover, it would be a more secure alternative since it guarantees the ability to provide good service levels and good access anywhere until the 2<sup>nd</sup> Sidney airport became viable. This first resort to SP reveals the benefits that flexibility adds to airport planning.

## 2.8.2 - Adaptive policymaking

Adaptive management approach was developed by McLain and Lee in the 1970s by a group of scientists working at the University of British Columbia [100]. Its solely purpose was to help environmental decision makers and managers increase their knowledge acquisition rates, facilitating information flow between policy actors and creating shared understandings amongst scientists, policy makers, and managers [101] [102] [103]. APM allows the implementation to begin prior to the resolution of all major uncertainties, as the policy is adapted over time based on new knowledge. It is an innovative way to proceed with implementation of long-term policies despite the uncertainties [7].

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<sup>19</sup> Insurance can be seen as a real option. Securing a site for the future is a way to protect against future uncertainties (it may never be needed but if it is, there is already a solution to deal with it). This option adds flexibility by granting the ability to expand Sidney’s air transport facilities

APM recognizes that fixed static policies are likely to fail in a constantly changing world. Therefore, APM is proposed as a generic approach to handle uncertainty since it allows planning adaptively and learning as time evolves [104]. APM process is split in two phases: a *thinking* phase where the adaptive policy is developed and an *implementation* phase where the policy is implemented, its performance is monitored and, if necessary, the policy is adapted. Unlike DSP, which has no concrete process, APM process comprises 4 different steps as described below [7]:

1. Stage settings: important objectives, constraints and policy options are identified during this step. Based on these, a definition of success of the adaptive policy can be given, which is needed in order to be able to decide when the policy needs to be changed;

2. Assembling basic policy: basic policy is assembled by specifying promising policies and identifying success factors for these policies;

3. Specifying rest of policy: (i) identifying policy's vulnerabilities and specifying mitigating and hedging actions that should be taken by the time when the policy is implemented to prevent its failure; (ii) translating success factors into signposts that should be monitored in order to guide the policy over time in case conditions change, specifying triggers that should lead to the implementation of defensive or corrective actions, or, in the worst case scenario, leading to a reassessment of the policy;

4. Implementation phase: policy remains active as long as the signposts signify that the policy is achieving its intended outcome. Otherwise, a reassessment is triggered reverting the policy-making process to step 1 (returns to step 1 with more knowledge of the situation).

### 2.8.3 - Flexible strategic planning

Although FSP's theoretical roots can be traced back to the late 1950s and the 1960s, it only started to gain momentum in the 1980s appearing for the first time in corporate planning during the 1990s as a branch of strategic management [98]. The changing economy was the main driver for FSP as planners started paying increased attention to uncertainty in SP [105] [106] [107]. FSP draws heavily on de Neufville's DSP, adding to it the notion of pro-active planning.

Airline network development and the increase in aviation's demand volatility required a more accurate method than forecasting to predict accurately future traffic demand. According to Burghouwt [98] pro-active planning and flexibility are required. FSP can be considered as part of the 'alternative paradigm of rational analysis' which does not discard the rational model completely, but rather adapts the rational model to real world circumstances as described in Table 4 [108].

**Table 4 - Alternative paradigm of rational analysis.**

<b>Rational model</b>	<b>Alternative paradigm</b>
Optimizing	Satisfy (non-optimizing)
Overwhelming data demands	Reduced data demands. Hard and soft data
Assumption of a single decision-maker with abstract objectives from which concrete actions can be deduced for implementation through a hierarchical chain of command	Facilitates planning from the bottom up
People are passive objects	People are active subjects
Implicitly ignores or attempts to abolish uncertainty	Accepts and deals with uncertainty

Source: adapted from [98]

One of the most important elements of FSP is the establishment of RO. Unlike traditional AMP that makes a single commitment to an expected future, FSP makes a more flexible commitment to deal with future uncertainties [109]. By choosing the possibility to postpone, delay, stage or abandon investments in an airport infrastructure, FSP minimizes irreversible commitments [98]. Besides RO, other characteristics can be distinguished in FSP:

- multi-future robustness and backcasting;
- contingency planning;
- scanning and experimenting;
- proactivity;
- diversification; and
- flexible organizations.

#### 2.8.4 - Adaptive approaches comparison

Regarding the construction of the NLA, it is necessary to define the more suitable ASP approach, taking into account to what extent these three approaches provide a clear planning process. An adequate starting point to do so is by analysing Table 5 that compares the three adaptive approaches previously described, providing general overview of their key features.

**Table 5 - Comparison of adaptive approaches.**

Aspect	DSP	APM	FSP
<i>Focus</i>	Flexibility in a plan created through RO	Starts from a vision of the decision-maker and creates a plan for realizing this vision and protecting it from failure	Extends the focus of DSP by adding proactive planning and contingency planning
<i>Types of uncertainties considered</i>	Emphasis on demand uncertainty, but other types of uncertainties could be considered as well via RO	Any uncertainty can be considered	Emphasis on demand uncertainties as driven by airline network developments, but in principle open to all types of uncertainties
<i>Consideration of different futures</i>	Through staged development	Through hedging and mitigating actions	Through scenario robustness
<i>Robustness of the resulting plan</i>	No direct consideration of robustness. A range of futures can be handled through RO	Explicit consideration of increasing robustness of plan through hedging and mitigation actions	Explicit consideration by using scenarios
<i>Flexibility of the resulting plan</i>	Guaranteed via RO	Addressed via the establishment of a monitoring system and pre-specification of responses	Guaranteed via RO and contingency planning
<i>Planning proves</i>	7 categories of activities specified, but their relationship to each other and how they constitute a planning process remain unclear	Clear planning process with a distinction between a thinking phase and an implementation phase	No clear process is specified

Source: adapted from [7]

As shown in the table above, and unlike traditional AMP, uncertainty is treated beyond demand forecasting in all three approaches, making use of techniques such as RO, scenarios and proactiveness. Use is made of these techniques in order to make the plan more robust regarding future uncertainties.

The definition or not of a process for their application is one of the main differences between these three approaches. Only APM has a defined process and a structure that, if followed carefully, will result in a complete adaptive plan liable to be implemented by police-makers.

DSP and APM both recognize the importance of committing only to a first set of actions in infrastructure planning. The construction of any component of an airport infrastructure (e.g. runway or terminal) takes several years and during that period, meaningful changes may occur rendering the investment is superfluous. These approaches suggest that investment in this type of infrastructure should be phased. It is intended to study in this thesis the phased investment options in the construction of the NLA.

### 2.8.5 - Unity is the solution

The appearance of these three approaches gave a new perspective in ASP. However, none of them individually presented as capable for the SP and construction of an airport. In 2008, Kwakkel *et*

*a.l.* [110] noticed that both FSP and Adaptive Policy-Making have a broader perspective on uncertainty than AMP since they not only look at demand uncertainties, but also at other factors that could hamper the success of the plan. The author recognized the need for two approaches in light of the continuing privatization and liberalization of the aviation industry.

Huber discussed the idea that FSP was inappropriate as well as the need of RO for airport development in India [111]. When deciding on building an airport the investor will have to choose between combinations of 3 dimensions of RO: the ability to expand in the future, the type of airport to build and the location (centralized or peripheral). In the authors' opinion, FSP does not address a wide scope of options, thus making it an inappropriate approach. A different strategy involving comparing the options that, a priori, seemed viable and determine their potential to generate growth in the Indian air traffic system, minimizing the risk at the same time was presented by the author.

In 2010 Kwakkel, *et al.* presented an integrated adaptive approach to replace AMP [7]. AASP is introduced as an improvement over the three separate approaches – APM, DSP and FSP. The author claims that these 3 approaches are complementary and that it is worth combining them into one – AASP. The main advantage of this new approach is the fact that it considers opportunities and includes pro-active actions. The plan to be put into effect consists in a set of actions that will be directly taken, split into an adaptive part consisting of the planned adaptations and a monitoring system that will trigger the planned adaptations.

By blending the best features of the approaches described above, it is possible to design an improved ASP approach benefiting from the strengths of each of these three approaches. The resulting approach will be better equipped to surpass the weaknesses of AMP than any of the three approaches individually [7]. Since these approaches are still in the conceptual stage, their merger into one is endorsed by researchers as they are able to focus their efforts on developing and testing a single approach instead of spreading their efforts over three different ones [98] [112].

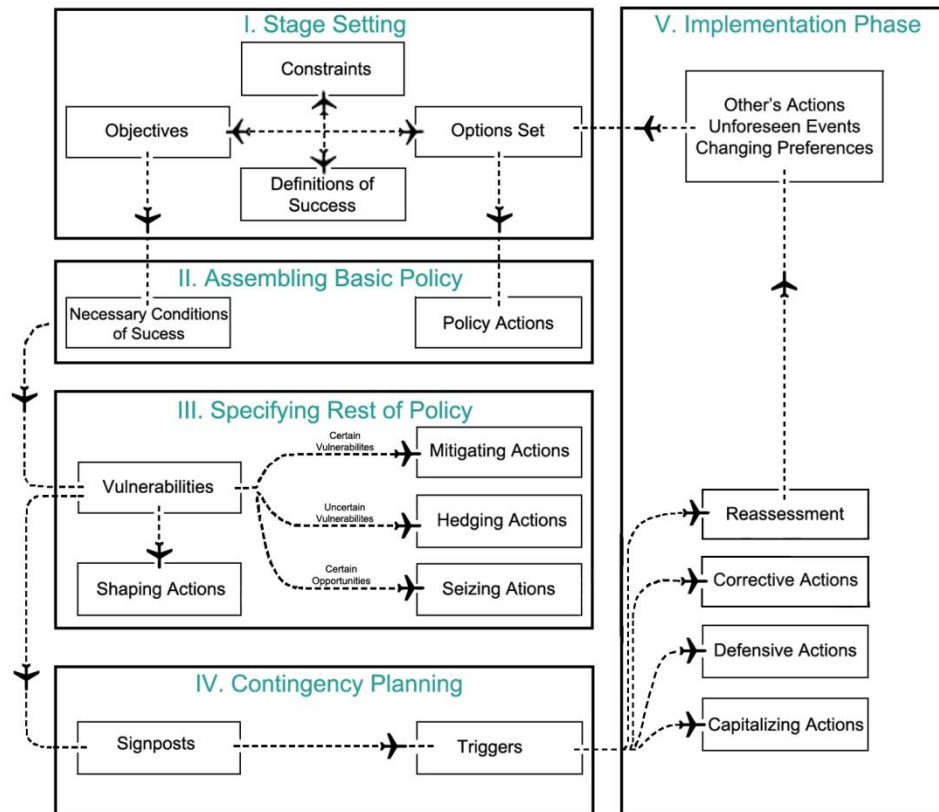
## **2.9 - Adaptive airport strategic planning**

AASP is an integrated approach for ASP aimed at dealing with uncertainties in a more efficient than AMP. APM is used as a starting point since it is the only approach with a well-developed planning process [7]. This approach comprises one of the key features of each of the three adaptive approaches addressed in section 2.8:

- ✓ The RO concept from DSP;
- ✓ The way RO can be used to create adaptive actions from APM; and
- ✓ The notion of pro-active planning from FSP.

APM can be expanded to capture future opportunities that can improve the policy's<sup>20</sup> success while avoiding vulnerabilities. Figure 6 shows AASP's process. Figure 6 presents the expanded APM framework.

Figure 6 - AASP.



Source: adapted from [7]

As shown in Figure 6, AASP is a stepwise approach composed by 5 steps which will be described next.

#### Step 1 – Stage Setting

The first step is a stage-setting one similar to the first step of APM. Objectives, constraints and available policy options are specified in this stage in order to obtain the desired outcomes.

#### Step 2 – Assembling the basic policy

After completing the first step, basic policy is assembled involving:

- I. Specification of a promising policy; and
- II. Identification of the conditions required for a successful basic policy.

#### Step 3 – Robustness

<sup>20</sup> The term 'policy' does not refer to government policies but, instead, it refers to airport plans or strategies, such as adding a runway or building a new terminal.

The focus of this step is to increase robustness by identifying in advance opportunities and vulnerabilities. Opportunities are developments that can increase the success of a policy while vulnerabilities are developments that decrease the performance of a policy making it no longer successful<sup>21</sup>. Taking actions now or preparing actions in advance so that they can be taken in the future are the two basic ways for preparing a policy for both opportunities and vulnerabilities<sup>22</sup>.

There are four different types of actions that can be taken in advance<sup>23</sup>:

- Mitigating actions (M): these actions intend to reduce certain adverse effects of a policy;
- Hedging actions (H): action that aim at spreading or reducing risk of the uncertain adverse effects of a policy;
- Seizing actions (SZ): actions taken to exploit certain available opportunities; and
- Shaping actions (SH): pro-active actions taken either to increase the odds that an external condition or event that could make the policy succeed will occur or to decrease the chance that an external condition or event that could make the policy fail will occur.

#### Step 4 – Contingency planning

In this step the robust basic policy is enhanced with the inclusion of adaptive elements. Accordingly, contingency planning expands the policy. The first element of contingency planning is the identification of signposts.

The set of opportunities and vulnerabilities defined in step 3 are the starting point for identifying these signposts<sup>24</sup>. Actions should be implemented if signposts reach their critical values so that the system maintains its proper functioning<sup>25</sup>.

As example, airport demand should be monitored closely because according to demand's evolution, modules can be added to the terminal if demand evolves favourably or postponed if demand evolves otherwise. RO can be incorporated in contingency planning. Opportunities that provide vulnerabilities should be considered at this stage.

Signposts can trigger four different types of actions:

- Defensive actions (DA) – actions taken after the fact to clarify the policy, preserve its benefits, or meet outside challenges in response to specific triggers that leave the basic policy remains unchanged;
- Capitalizing actions (CP) - actions taken after the fact to take advantage of opportunities that further improve the performance of the basic policy;

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<sup>21</sup> A rapid increase in demand allowing for an airport to expand faster than predicted is an opportunity while a decrease in demand can turn out to be a vulnerability making the investment in capacity expansion superfluous.

<sup>22</sup> Preparing action is considered in step 4.

<sup>23</sup> In any of these types of actions, RO can be used.

<sup>24</sup> Signposts specify information that should be tracked to determine whether the policy is achieving its conditions for success.

<sup>25</sup> Signposts are developed for monitoring changes in the system. They work as triggers for contingency plans when their critical values are reached.

- Corrective actions (CR) – adjustments to the basic policy in response to specific triggers; and
- Reassessment (RE) – a process to be initiated or restarted when the analysis and assumptions critical to the policy's success have clearly lost validity.

#### Step 5 – *Implementation*

The 5<sup>th</sup> and final step involves setting the plan into practice by implementing actions to be taken immediately (steps 2 and 3) and establish a monitoring system (step 4).

The process works as a cycle collecting information from signposts to measure what policy actions must be put into practice. After the initial actions are implemented the process is suspended until a trigger event occurs. Different triggers will require different defensive or corrective actions. If these are inadequate, the entire policy might have to be reassessed or abandoned. In that case, previous experience will positively contribute to the creation of a new one accelerating the new policymaking process.

## **2.10 - Flexibility in airports: case studies**

Flexibility can also be incorporated to solve short-term capacity problems. A new airport takes several years to be constructed. Therefore, short-term solutions to cope with capacity problems may prove useful. Several examples are presented next.

De Neufville explained the need for hybrid configurations to meet different types of traffic [52]. The notion that airport buildings are just terminals is no longer appropriate and new terminals must be highly flexible for expansion and able to deal with the changes in the percentage of transfer passengers. The change of airlines and airport operators from governmental ownership to privatized companies is one of the main factors responsible for the new design paradigm. Airports are now transfer points instead of only terminals as a huge percentage of the traffic accounts for passengers changing from one plane to another. To efficiently deal with this type of traffic the need for flexibility must be recognized.

Planning for flexible development of passenger buildings is the solution to capture transfer passengers' traffic. Midfield passenger terminals provide maximum convenience to passengers and aircraft by minimizing the distance passengers need to move between aircrafts and clustering aircrafts around the building [113]. These midfield passenger buildings will be remarkably large to deal with the peaks of arriving and departing passengers as well as allow concurrent parking of several aircrafts. The inside of these buildings will be small to allow passengers to connect rapidly between flights.

Phua developed a master thesis in an attempt to identify the optimal combination of airport passenger buildings and internal transport technologies for both passengers and their bags recognizing the need for flexibility in airport design [114].

Smit focused on the Schiphol airport expansion applying the option game approach and claiming that this approach could also be used in infrastructure investments as well as in other areas such as: corporate infrastructure, platform, R&D, electronics and pharmaceuticals [115]. The author valued the airport expansion in a competitive context as an option game concluding that, compared to traditional valuation, RO games method can not only accurately evaluate an individual investment, but can also shape the strategic competitive pressures to invest for different types of investment strategies. Furthermore, the author claimed that valuation and SP should interactively complement each other.

In 2007, Gil developed a multiple case-study of 12 options embedded involving 5 projects all concerning an airport expansion programme [116]. The 12 options are spread through the airfield, the train system, the baggage system, the car park and the terminal building one. The analysis developed uncovered a trade-off commonly seen in the RO world. The author concluded that passive safeguarding is more appropriate in a scenario with high uncertainty and low modularity as opposed to active safeguarding (more valuable when uncertainty is low and modularity is high).

Chiara *et al.* applied the multi-least-squares Monte Carlo technique to determine the fair value of an airside expansion at Lambert Field [117]. The authors found out that the levels of demand forecast never materialized considering the forecast provided by the Master Plan Supplement to be over-optimistic. The authors concluded that the part of the Lambert expansion project that was demand-driven was indeed responsive to the drop in demand. Once traffic returns to St. Louis, runway 11-29 (completed in 2005) will be an invaluable asset. It may even provide competitive advantage.

Ohama studied a runway extension project at the Tokyo International airport through a RO analysis [118]. This project intended increase the airport capacity, bringing a major impact on the overall economy of the country. To evaluate this project, three types of designs were considered (2 without flexibility and one with flexibility). The author concluded that flexible design allows project optimization as well as reducing losses in airport systems.

Morgado, *et al.* used the example of the Mexico City International Airport (AICM) to analyse an expansion investment [119]. AICM was working close to its capacity limit and in a scenario where demand kept growing. The major sources of uncertainty over the life span of the investment project are: political issues and government policy, construction and environmental and the demand during operation. The binomial lattice model was used, modelling demand uncertainty, and obtaining an NPV of -71,15 US\$ million. Two alternatives were presented: flexibility in the runways (option to build later the 2<sup>nd</sup> runway) and flexibility both in runways and in one terminal (increasing capacity when needed).

The option values in both alternatives were US\$ 64,2 million and US\$ 241,62 million respectively. Both alternatives clearly demonstrate the true value of RO making an unattractive project into a very interesting one. This idea meets the authors need to motivate everyone involved in airport infrastructure expansions to abandon the traditional deterministic way of deciding, as well as to demonstrate the potential of RO.

In 2012 Pinon, *et al.* captured and valued the flexibility of airport capacity-enhancing technology investments using RO analysis [120]. The different factors that have impact on the strategic value of airport technology portfolios by changing traffic demand. The case study considered an investment window of 15 years, where investments can be done by the airport at years 5 and 10. Four different scenarios are presented with differences in the decision to invest or not as well as the investment dates. The author claimed that the loss in revenues can be seen as an incentive by the airport to address the congestion issue.

# REAL OPTIONS

## 3.1 - A new approach to value flexibility

Infrastructure investment analysis has been an active field of research in the last decades. The DCF method prevailed when there was the need to calculate the value of a project. The critical variable was the choice of the discount rate that would allow transforming future cash flow in present values. The method was seen as the most adequate and suitable to capture the project's real value, although other alternatives existed, e.g. capital cash flow, more suitable to large investments with variable debt structures [121].

The rationale for incorporating flexibility in infrastructure projects is rather simple, unlike the empirical application which can be extremely complex. The principle is that the project should have the necessary flexibility to adapt to future changes, i.e., at the design stage it is necessary to incorporate flexible options (RO) that would allow the infrastructure and/or the service, to be adapted to a certain change [122]. A casebook example is the 25<sup>th</sup> of April Bridge over the Tagus River in Lisbon, Portugal. The initial project included only one road deck for cars, but the sub-structure was reinforced to accommodate a future second deck. A second deck was added some decades later, but instead of a road deck, the new deck offers rail services [123].

How to value this flexibility when calculating the economic value of the project? Simple DCF techniques would account for the cost of building this flexibility, but not with the benefit of using the flexibility according to an adaptable timing.

## 3.2 - Real options: from financial to real options

### 3.2.1 - The beginning

The foundation of financial options (FO) theory took place in 1900 by the French mathematician Louis Bacheliers – 'The theory of speculation' as argued by Chiara *et al.* [117] [124]. Around 1960, Samuelson recognized the need to bring the value of the uncertain payoffs back to the present. Despite all his efforts and hard years of work (published in 1965) he did not solve the discount rate problem [125].

The field of capital budgeting remained stagnant for several decades, until recent developments in RO theory that provided new tools and unlocked the possibilities to revolutionize the

field. RO roots have their origin in financial stock options pricing<sup>26</sup>. These FO are contracts sold against a certain premium giving the buyer the right, but not the obligation, to buy a stock against a predetermined price [126].

### 3.2.2 - The need for a new approach

Myers, Trigeorgis and Manson pointed out the main problems and limitations of DCF method concluding that this method could lead to wrong investment decisions [127] [128]. The main problems regarding DCF method are the expected future cash flows which do not adequately reflect the flexibility within the investment and operation of the asset. Besides, the cash flows at different points in time usually require different discount rates to appropriately reflect their risk. Furthermore, DCF techniques favour short-term projects in relative certain markets over long-term and relatively uncertain projects [129].

The idea of RO comes from corporate finance and provides a way to think more rationally about capital investment decisions when there is significant uncertainty related to the potential benefits.

### 3.2.3 - The gap between finance theory and strategy planning

In the late 1980s, several reviews emerged saying that there was no link between financial theory and SP. The concept of incorporating flexible options in infrastructure requires a SP of the system. What can the future bring? What types of services or changes in current services might be necessary? The answers to these questions were given by Myers who discussed this apparent disconnection and reached the conclusion that SP would benefit from tools provided by the finance theory, as long as properly applied [127].

RO analysis presents an important step bridging the gap between these two themes<sup>27</sup>. Trigeorgis and Mason clarified that option valuation can be seen operationally as a special, economically corrected version of decision-tree analysis that is better suited in valuing a variety of corporate operating and strategic options [128]. Ford *et al.* stated that *“Competitive advantage comes from the creation of valuable resources through long-term investment in value-creating activities (...). So, RO are used somewhat metaphorically to denote the opportunities that result from a particular set of path-dependent investments”* [130].

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<sup>26</sup> A financial stock option example is discussed in Annex 1, in order to explain the basics of FO theory and relate it to the RO approach.

<sup>27</sup> To elucidate the reader concerning bridging the gap between finance theory and strategic planning, see Myers [127].

Myers' argument was supported by Barwise *et al.* and during the next decade and the beginning of the 21st century, several books regarding these topics were published [131] [132] [133]. In his paper, Myers acknowledged that '*Finance theory and SP could be viewed as two cultures looking at the same problem*' [127].

### 3.2.4 - Similarities between options

In 1969, Black wrote the partial equation and, together with Scholes, found a single-equation solution that provided the option value – later called the Black-Scholes formulae. Some years later, Merton added the missing ingredient – arbitrage [127]. But it was not until 1973 that Black and Scholes published the equation able to quantify the value of a European financial option [4]. The Black, Merton and Scholes formulae uses an entirely different approach to work around the discount rate dilemma. They established the value of an option by constructing a portfolio of traded securities, known as a tracking portfolio, which has the same payoffs as the option. This work awarded them the Nobel Prize in Economics in 1997<sup>28</sup>.

Myers, who first coined the term RO, observed that future investment by corporations is discretionary and, thus, it is analogous to a financial option where an investor holds a claim to buy or sell an underlying financial asset at a potentially favourable price, and has the right to make this trade only if it will in fact be profitable [127]. He established the term 'RO' to emphasize that investment opportunities are (or involve) options on real assets, as opposed to financial assets [134]. One year passed and Ross was already discussing the theory of RO valuation based on his analysis regarding risky projects. He considered the inherent potential investment opportunities as a real option [135]. However, there are several analogies between financial and RO as is shown in Table 6.

**Table 6 - Analogy between FO and RO.**

FO	RO
Time to Maturity	Time until the investment opportunity disappears
Exercise Price	Costs of irreversible follow-on investment
Volatility of Stock Return	Variability of growth in project value
Share Price	Present value of expected CFs
Risk-free rate of return	Risk-free rate of return
Dividend	Value lost by waiting to invest

Source: Lint and Pennings [129]

As Ross claimed, by considering investments as options, the emphasis of the analysis goes from the choice of discount and interest rates towards discussing risks and how to deal with them [135]. In the field of infrastructure, this change in the paradigm can be extremely useful. Like FO, RO value depends on five main variables, plus an indirect variable – the dividends [133] [136]:

<sup>28</sup> To know more about the prize, see the following link:  
[http://www.nobelprize.org/nobel\\_prizes/economics/laureates/1997/press.html](http://www.nobelprize.org/nobel_prizes/economics/laureates/1997/press.html).

1. *Value of the underlying risk asset* – project, investment or acquisition in RO case. An important difference between financial and RO is that the owner of FO cannot affect the value of the underlying. At the same time, managers operating a real asset can increase its value;
2. *Exercise price* – Money invested to exercise the option in case of ‘buying’ the asset or else the money that will be received if the company is ‘selling’ the asset;
3. *Time to expiration of the option* – investment opportunity is only valid until the expiration date (depends on both technology and contracts);
4. *Standard deviation of the value of the underlying risk asset / uncertainty* – unpredictability of future cash flows that is related to the asset;
5. *Risk-free rate of interest over the life of the option* – theoretical interest rate returned in case of an investment that is risk-free;
6. *Dividends* – the cash outflows and inflows over the assets life. These cash flows are similar to dividends on a stock.

Two types of options are commonly traded in the financial stock market: call and put options. In the first case – call options – the owner of the contract holds the right, but not the obligation, to buy a stock at a predetermined price within a certain time. In the second one – put options – the exact opposite happens, the owner has the right to sell a stock against a predetermined price at a specific time [137]. Table 7 illustrates how call and put option value changes when each of the variables increases.

**Table 7 - RO value characteristics.**

Increase in variable	Call option value	Put option value
Asset value	Increases	Decreases
Exercise price	Decreases	Increases
Interest rate	Increases	Increases
Time to expiration	Increases	Increases
Volatility	Increases	Decreases
Dividends	Decreases	Increases

Source: adapted from [138]

Two types of FO should be highlighted: European options (options that can only be exercised at their maturity date) and American options (options that can be exercised at any time until the maturity date) [139]<sup>29</sup>. What changes in American options is the time in which the owner of the contract can exercise his option (variable) – he is no longer tied to a one-time event (maturity date).

<sup>29</sup> A curious fact is that in the European market most of the options traded are American options.

### 3.2.5 - Beyond financial options

In the late 1970s and beginning of the 80s, the field of RO suffered successive developments: the expansion of the areas of application and the emergence of diverse options. Margrabe valued a compound option (option to acquire another option – values the option to exchange one asset for another within a certain period) [140]. This is relevant in financial markets, but with limited application to the field of physical assets. Furthermore, Carr valued sequential exchange options, involving an option to acquire a subsequent option to exchange the underlying asset for another risky alternative [141]. Mason and Merton as well as Kasanen and Trigeorgis maintained that RO may be valued similarly to FO, even though they may not be traded, since in capital budgeting we are interested in determining what the project CF would be worth if they were traded in the market [142] [143] [144].

Luehrman linked the variables of a call option to the variables of an investment opportunity [145]. A change in any of the variables will alter the value of the option in the respective investment (e.g. higher expenditure lowers the option value; greater uncertainty increases the volatility rate → potential higher values achievable → increased option value).

RO and investment opportunities present several similarities. Figure 7 illustrates the mapping of investment opportunity onto a call option. The example described is relative to a European call option, which is easier to understand since it can be exercised only on the maturity (or expiration) date [139].

Investment opportunity	Variable	Call option
Present value of a project's operating assets to be acquired.	— <b>S</b> →	Present value of a project's operating assets to be acquired.
Expenditure required to acquire the project assets	— <b>X</b> →	Expenditure required to acquire the project assets
Length of time the decision may be deferred	— <b>t</b> →	Length of time the decision may be deferred
Time value for money	— <b>r<sub>f</sub></b> →	Time value for money
Risk of the project's assets	— <b>σ<sup>2</sup></b> →	Risk of the project's assets

Figure 7 - Mapping an investment opportunity onto a call option.

Source: adopted from [145]

Infrastructure investments are similar to exercising an option or a share of stock. Firstly, the investment is composed for a certain amount of money, which corresponds, in this case, to the exercise price (X) of the option. Secondly, the asset present value that will be acquired corresponds to the stock price (S) and thirdly, the time for which each investment can be deferred without losing the opportunity resemble the option's time to expiration (t). The uncertainty concerning future value of project cash flow corresponds to the standard deviation (σ<sup>2</sup>). Finally, the value of money is represented by the risk-free rate of return in both cases. The following table sums up this information<sup>30</sup>.

<sup>30</sup> For further information regarding mapping an investment opportunity into a call option see Luehrman [145].

Mapping an investment opportunity as a call option helps managers to better understand the role played by uncertainty when it comes to make a decision, as well as recognizing the asymmetry in option's net payoff [135].

Since other approaches failed in capturing managerial flexibility, RO framework was extended to different fields and theory was tested to validate and evaluate the association between physical investment and flexibility [146]<sup>31</sup>. In 1999, Amram and Kulatilaka helped managers to make use of their own option right to make management decisions in areas such as R&D project selection, strategic investment and infrastructure – being this last one the most relevant for this project [132].

By applying option pricing theory and the financial market rules to the evaluation of non-trading assets they managed to do so. Two main reasons explain why RO framework is suited for real asset application: the payoffs of the contingent investment decision can be tailored to every situation and RO framework illuminates the nature of risk embedded in real assets. Being so, RO approach incorporates the effects of market-priced risk and private risk when it comes to valuing strategic investment opportunities [132].

The entrance to the new millennium, with technological advances allowed bypassing the limited applications of RO as is synthetized in Figure 8.

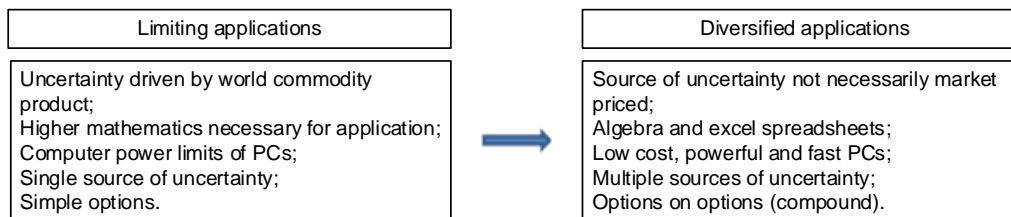


Figure 8 - Bypassing limitations.

Source: adapted from [133]

### 3.3 - Real options framework

Baldwin and Trigeorgis proposed a solution to bypass the underinvestment problem and, at the same time, to restore competitiveness by developing specific adaptive capabilities - viewed as an infrastructure - for acquiring and managing corporate RO: the RO framework [147]. The companies need to behave more proactively contrasts sharply with the paradigm '*the future is to be predicted, not chosen or created*' [148]. Instead of forecasting, RO way of thinking encourages managers to create opportunities to be used in the future as uncertainty is resolved.

The main questions that RO theory attempts to answer are [149]:

- What are the future alternative actions?
- When should these actions be chosen to maximize value based on conditions' evolution?
- How much is the right to choose an alternative worth at any given time?

<sup>31</sup> Annex 2 contains a literature review on RO application to different fields.

The ability to roadmap future actions is the key issue regarding RO. By mapping out both uncertainties and decisions over time, RO provides an appropriate way to track not only value creation but also the risk profile of a project or a portfolio of projects. RO framework is characterized as follows [150]:

- Focus corporate managers' attention on the value of flexibility;
- Awareness to answer to new information over time;
- Flexibility affects both present and future decisions;
- Increases the effectiveness of areas such as: planning investment and operating strategies;
- Management becomes more reactive (in the sense of responding effectively as uncertainties are resolved over time) and more proactive (building flexibility into projects).

Ford *et al.* recognized the need for a new approach when they claimed that '*successfully managing dynamic, uncertain project conditions require a proactive approach*' [151].

## 3.4 - Taxonomy of real options

### 3.4.1 - Types of real options

Trigeorgis focused explicitly on the nature of RO interaction, pointing out that the presence of subsequent options can increase the value of the effective underlying asset for earlier options, while the exercise of prior RO may alter the underlying asset itself, hence the value of subsequent options on it [128]. Thus, the combined value of a collection of RO may differ from the sum of separate option values [144]. The author distinguished several types of options, taking into account differences in flexibility, dividing them into seven categories:

- Option to defer;
- Staged investment option;
- Option to alter operating scale;
- Option to abandon;
- Option to switch;
- Growth option;
- Interacting option.

These categories belong to four groups of options such as: growth, contraction, switching and contractual. A detailed description, the main fields of application, the type of flexibility they grant as well as a guide to literature can be found in Table 8.

Table 8 - Taxonomy of RO.

Option	Description	Main Fields of Application	Type of Flexibility	Guide to Literature
<b>Defer</b>	Regards profitability on investing. Possible future conditions may be preferable comparing with present situation. This option exists when management is able to leave an open door to investment opportunities, for a certain period. American Call-like option.	Natural Resources Industries, Real Estate Development, Farming.	Upside Potential.	Tourinho [152]; Titman [153]; McDonald and Siegel [154]; Paddock, <i>et al.</i> [155]; Ingersoll and Ross [156]; Dixit [157].
<b>Staged Investment</b>	Some investments can be staged in order to create growth and abandonment options. This allows viewing each stage as an option on the value of subsequent stages (compound option).	R&D intensive industries, Capital-intensive projects and start-up ventures.	Upside Potential and Downside Protection.	Brennan and Schwartz [158]; Majd and Pindyck [159]; Carr [160]; Trigeorgis [83].
<b>Alter Operating Scale</b>	Regards changes in market conditions in order to make the most of them (either increase profits or minimize losses). If market conditions are favourable, the company will want to increase the output level by making an investment to scale-up the production plant. On the other hand, if market conditions are unfavourable, the company must have the ability to shut-down production. Similar to call options.	Natural Resources Industries, Commercial Real Estate and other cyclical industries.	Upside Potential and Downside Protection.	Brennan and Schwartz [158]; McDonald and Siegel [161]; Trigeorgis and Manson [128]; Pindyck [162].
<b>Abandon</b>	Management's ability to abandon a current operation permanently - recover the salvage value of the asset. Similar to American put options.	Capital-intensive industries (e.g. airline industry, railroad and financial services)	Upside Potential.	Myers and Majd [163]; Sachdeva and Vanderberg [164].
<b>Switch</b>	Options that create both process and product flexibility. By combining call and put options, the owner is able to switch between two or more modes of operating.	Facilities highly dependent on one input (e.g. oil, or any other commodity).	Downside Protection.	Margrabe [140]; Trigeorgis [83].
<b>Growth</b>	Exist when early investments (e.g. in R&D) create the opportunity for future revenues. Compound Options whose value depends on a pre-existing option. Similar to European or American Call.	R&D.	Upside Potential and Downside Protection.	Myers [165]; Kester [166]; Trigeorgis [167]; Pindyck [162]; Brealey and Myers [138]; Chung and Charoenwong [168].
<b>Interacting</b>	Combination of options above.	Combination of options above.	Depends.	-

Source: adapted from [134]

### 3.4.2 - Growth options

These options which are similar to financial call options are the most frequent type of RO. The investment made (either today or in the past) is the 'cost' of the option. This puts the company in a scenario where future investments can be made to increase their earnings. Like FO, some growth options have a limited horizon. However, most of these options do not have a fixed maturity and are only exercised when the cost of waiting is higher than the benefits from waiting for additional uncertainty to be solved. Growth option also differs from FO because most of growth opportunities involve a sequence of investments over time. Options are created upon exercising early options – compound options. Pindyck suggests that growth options should account for at least half of a company's value [162].

### 3.4.3 - Contraction options

These options (contract or abandon) can have impact on shareholder value. Production at a mine or refinery plant can be scaled-down to answer to the decline in output prices for example – allows minimizing losses [134]. The costs of contraction or abandonment are related to the degree to which the company invested up-front in flexibility. Abandon a production can be staged due to, in the majority of cases, environmental issues.

### 3.4.4 - Switching options

A company is able to make several adjustments in order to take maximum advantage of market conditions by designing flexibility into production systems. Using only one production line can be inefficient if that product value is increasing and the company could be producing more units by altering the form of involvement [169]. Therefore, having the flexibility to switch to two production lines will allow the system to improve its performance. Likewise, if the value of a service is decreasing, the system can reduce the number of production lines or even change to another product whose market value is higher than the current one being produced. These options should be within reach of the most competitive companies. Unlike FO whose, most of the time, offer a binary choice, RO typically involve a choice among several alternatives available.

### 3.4.5 - Contractual real options

Contractual RO are options embedded in contracts (e.g. locking in prices and lead times for delivery). Contraction and switching options may also appear in contractual form. In these types of options, flexibility is traded through options in contracts – only firms that have invested in flexibility and able to deal with a diversity of customers and products can take a profitable advantage of this type of flexibility [134].

## 3.5 - Real options 'on' projects and 'in' projects

### 3.5.1 - Real options 'on' projects and 'in' projects overview

RO can be categorized as 'on' and 'in' the projects [113] [122]. The options that deal with technology as a 'black box' are RO 'on' projects - these are FO taken on technical things. On the other hand, options created by changing the design of a technical system are options 'in' projects. RO 'in' projects are the latest expansion of RO theory into physical systems design [170].

### 3.5.2 - Real Options ‘on’ projects

RO ‘on’ projects regard flexibility associated with uncertainty [122]. This type of RO deals with the entire infrastructure as one single system. The options are applied over this system. These options are generally applied if the source of uncertainty is related to market factors, e.g., changes in demand.

### 3.5.3 - Real Options ‘in’ projects

RO ‘in’ projects are options that can be created within the design of the system or projects. The infrastructure is no longer a single system, but it is divided in several sub-systems. The options are applied within these systems. The data available for this type of RO is far less accurate than the one available to RO ‘on’ projects. Moreover, there is a need for an appropriate analysis framework due to the specific features of these types of options (‘in’ projects). RO ‘in’ systems also require a profound understanding of technology. Project managers must have technical understanding and be strategically ready for the project to make the most of these options [112]. A really simple example is the spare tire on a car – the car owner has *‘the right, but not the obligation’* to change the tire whenever he wants to. Table 9 summarizes the comparison between RO ‘on’ and ‘in’ projects.

**Table 9 - Main differences between RO ‘on’ and ‘in’ projects.**

<b>RO ‘on’ projects</b>	<b>RO ‘in’ projects</b>
Value opportunities	Design flexibility
Important valuation	Important decision (go or no go)
Relatively easy to define	Difficult to define
Interdependency/Path-dependency less an issue	Interdependency/Path-dependency an important issue

Source: adapted from [122]

### 3.5.4 - Contractual options “in” projects

Contractual options “in” projects were created to address the problem of flexibility in particular cases of infrastructure, or, in particular cases of infrastructure delivery models: public-private partnerships (PPP). When it comes to infrastructure development, PPP arrangements are considered relation-specific investment since both the public and private sector are better off handling the project together than by themselves [171]. This type of relationship carries out a critical issue when it comes to the transaction cost. Every party wants to take advantage of the slightest opportunity available and greediness might ruin the project. Until recently, long-term rigid contracts were the best way to reduce as much as possible the transaction cost [172].

Infrastructure projects have a high uncertainty associated with them most of all due to the long lasting lifecycle. There is no accurate way to predict future downside risks at a pre-project planning phase since these projects require a long-term commitment. A proactive uncertainty management is the solution since it allows incorporating flexibility into the contracts.

Chiara and Kokkaew presented a new approach to address the concerns highlighted above - contractual flexibility analysis (CFA) [173]. This approach enables the evaluation of the endogenous flexibility from the perspective of a project level, since it refers to the endogenous interdependent flexibility within a contractual structure of multi-shareholders. Not to incorporate flexibility in long-term contracts has damaged both public and private sectors. Thus, with CFA it is now possible to adjust the allocation of risk during the lifecycle of the project.

## **3.6 - Valuation tools: techniques to value real options**

### **3.6.1 - Valuation tools: overview**

There are five main techniques to valuing options: the Black-Scholes Option Pricing Model (BSOPM), the Binomial Option Pricing Model (BOPM), the Risk-Adjusted Decision Trees (RADT), the MSC and, finally, Hybrid Real Options (HRO). The main specifications, advantages and disadvantages, are briefly addressed below as well as a comparison of the five valuation tools.

### **3.6.2 - Black-Scholes option pricing model**

The model developed in 1973 by Fischer Black and Myron Scholes requires several assumptions in order to become applicable [4]. First of all, this model can only be implemented if the options are of the European (call and put) kind, since it requires a fixed decision date. Secondly, the limiting distribution has to be the Normal Distribution. Furthermore, the price process needs to be continuous. This model is not an alternative to the Binomial Model but a limiting case of that model [174]. When constructing a tracking portfolio, the value of the option is established - the portfolio has the same payoff as the option. The main advantage of this model is the simplicity required to calculate the value of the option as it is only needed to plug six variables into the formulae - initial value of the underlying asset, time until maturity, exercise price, difference between capitalization rate and the percentage of expected change in the value of the underlying asset, continuous compound risk-free rate of return and, finally, the volatility in the underlying asset [134].

The disadvantages concern some of the assumptions (price, volatility and duration) as they limit the use of this approach as well as the requiring advanced financial knowledge. The formulae lacks in transparency and intuition, which comes across as a black-box [134]. Therefore, it becomes really difficult to apply this approach to large-scale complex engineering projects, such as an airport.

### **3.6.3 - Binomial option pricing model**

The Binomial Model allows the creation of a simple representation regarding the evolution of the underlying asset and it is based on risk-neutral argument. The multiplicative Binomial Model of uncertainty is described as follows: the asset has an initial value  $X$ . In the next time period, its value

either moves upwards being multiplied by an increasing factor -  $u$  - with a probability of  $p$  ( $Xu$ ), or moves downwards being multiplied by a decreasing factor -  $d$  - with a probability of  $1-p$  ( $Xd$ ) - the underlying asset can only take one of two possible values (binomial). In the following period, the value may have one of the three following values:  $Xu^2$ ,  $Xud$ ,  $Xd^2$ . By allowing for a sequence of periods with such binomial movements, a large set of paths (Binomial 'tree' – see figure 9) can be generated and will closely approximate all possible value changes that would occur to the underlying asset during the life of the option [175].

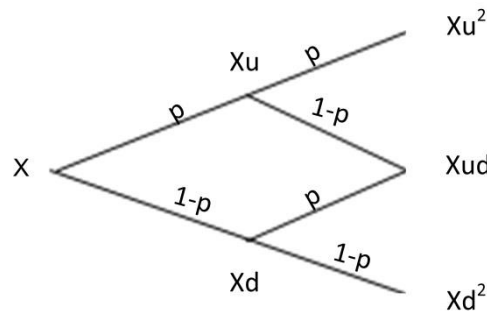


Figure 9 - Example of a Binomial tree

The main advantages of the BOPM are the effectiveness of the model if there is only one uncertainty and providing to project managers an appropriate evolution of the underlying asset. Moreover, it allows estimating the value of several option futures, including the early exercise of an American Option. However, this model is not easy to use, as it also requires advanced financial knowledge, like the Black-Scholes Model. It is difficult to conduct if there are several uncertainties at the same time. The Binomial Model can be defined as a simplified discrete-time approach to valuation of options when compared to the BSOPM [176]. Triantis stated that *'the Black-Scholes and binomial option valuation models are widely used in practice for valuing growth options'* [134].

### 3.6.4 - Decision analysis: risk-adjusted decision trees

DA is a more discretionary methodology since it relies on subjective assessment of probabilities, discount rates and decision-makers preferences concerning a specific objective – aligned to maximize the shareholder wealth [177]. This methodology is able to better map more complex problems. Recourse to DA has become an appealing alternative because, in addition to being able to deal with multiple uncertainties, it also enables decision-makers to develop insights on RO and to estimate the approximate value of flexibility - especially those projects with sequential decision opportunity and variable outcomes over time [178]. It becomes a really useful methodology when a drastic change in the system occurs and it is not necessary to possess as much financial knowledge - key advantages when compared to both previously mentioned models. On the other hand, this methodology does not provide the true value of projects being too complicated to interpret the results when developing several branches. When compared with the BOPM, the RADT valuation model has two major advantages: the ability to take into account the risk from the shareholders' point of view and a simpler layout, since at each event node in the tree, the decision node is implicit [134].

### 3.6.5 - Monte Carlo simulation

The MCS methodology is, as DA, able to deal with several uncertainties. A number of different values for the underlying uncertainties are generated based on distributions (probabilities) that are adjusted for systematic risk. The expected value of the option is then calculated, and a risk-free rate is used to discount this expected value back to the initial date [134]. The optimal strategy investment is determined at the end of each path, where the payoff is calculated.

As opposed to the previous models, Monte Carlo is a simulation model. Being so, its key advantage is the ability to deal with multiple uncertainties, the fact that it becomes quite helpful for problems with '*path-dependency*' (future outcomes or decisions depend on decisions made at earlier points in time) [179]. Furthermore, with the recent computer technology developments, it is now possible to easily construct large computer simulations. These main advantages make this model user-friendly as well as really simple to explain the results graphically to the decision-maker. The last advantage lies in the use of spread sheet software such as Microsoft Excel® as this is the tool for conducting MCS [180]. On the downside, it may lack some transparency to management when compared with the Binomial or Decision Tree models. In addition to this, it is a hard methodology to implement the results since simulation models use a subjective discount rate (as referred above) and do not incorporate financial market information [180] [181].

### 3.6.6 - Hybrid real options

New projects or products with both technological and financial risks inherent need solid methods for valuing prospective investments, so that they can justify their development strategies. Traditional methods are mechanically and conceptually inadequate for risky projects. This valuation model is more effective for large, risky projects [182]<sup>32 33</sup>. Neely developed a different approach to this type of problems by considering two distinct types of risk: project and market [183]. Project risks regard uncertainty associated with the project in study and market risks concerns the market price of the product. Each of these two types of risk has different implications concerning the discount rate. Project risks, unique to the project by definition do not require an adjusted discount rate to reflect risk since managers can diversify their investments to compensate losses. Being so, to analyse these risks a DA is used with a constant discount rate. On the other hand, market risks cannot be avoided with the appeal to diversification. Only options analysis can cope with these types of risks once the level of market risks change when a project is actively managed [182]. A risk-neutral valuation is a process whose net effect is to adjust the project outcomes so that the risk-free rate can be applied<sup>34</sup>. The

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<sup>32</sup> Conceptually - because they ignore the reality of management control.

<sup>33</sup> Mechanically - because they assume a single CF, also assuming that the value of this average CF equals the average value of a range of CFs.

<sup>34</sup> To learn more about this issue see Hull [185].

combination of Options Methods for market risks with DA for project risks is seen as a practical approach to value RO.

The main advantages of this unusual method are: combining the best of DA and Options Analysis into a practical means of accurate valuation method and the possibility of choosing the discount rate for the valuation. Moreover, by dividing the valuation process into a technical and a financial part, experts can handle each of these independently. This facilitates the implementation of a system approach to project valuation [184]. HRO lacks of elegance from a theoretical point of view.

### 3.7 - Comparison between models

To obtain a more detailed qualitative analysis as possible, the choice of the validation tools should not fall into only one. The BSOPM was excluded from the outset since it cannot handle more than one type of uncertainty. On the other hand RADTs, MCS and HRO are the best candidates to apply in infrastructure projects. These tools allow not only to compare the value of the RO incorporation in the projects, but also to measure different gains depending on the valuation tool used. Each one of the models upsides and downsides are summarized in Table 10.

**Table 10 - Valuation methods overview**

Methodologies	Upside	Downside
<b>BSOPM</b>	Simple to calculate the option value.	Only applicable to European Options; Only works with the Normal distribution; Require advanced financial knowledge; Assumptions required limit the use of the model (price, volatility, duration); Only able to deal with one factor of uncertainty.
<b>BOPM</b>	Effective when dealing with one factor of uncertainty; Provides project managers with an appropriate evolution of the underlying asset; Estimates the value of several option futures.	Require advanced financial knowledge; Only able to deal with one factor of uncertainty.
<b>RADT</b>	Allows mapping complex problems; Able to deal with multiple uncertainties; Enables decision-makers to develop insights on RO; Useful in the case of a possible drastic change in systems.	Does not provide the true value of the project; If the number of branches is high, it becomes too complicated and unclear.
<b>MCS</b>	Demonstrates graphically the analysis results; Able to deal with multiple uncertainties; Not required to understand financial theory; Helpful for problems with ' <i>path-dependency</i> '; User-friendly multiple document interface.	Lacks transparency; Hard methodology to implement with American options.
<b>HRO</b>	Able to deal with multiple uncertainties; Combining the best of DA and Options Analysis; Independent handling of technical and financial parts.	Hard methodology to implement (it requires highly sophisticated mathematical modelling skills).

Once only one type uncertainty will be modelled in this research – demand – the BOPM is one of the chosen models. To obtain a more accurate result, simulation software will also be used. In chapter 5 this topic is thoroughly analysed.

# THE NEW LISBON AIRPORT

## 4.1 - ANA Aeroportos de Portugal, SA

The company ANA arises due to the separation of ANA Airports, EP in 1998. While ANA is a company focused on airport management, the other company resulting from this division, NAV, EP is geared for air navigation [186].

ANA manages three companies that will strengthen its capacity to respond to a market in constant evolution. In the end of 2011, ANA held a 70% share of the ANAM-Airports and Air Navigation Madeira, which is responsible for the management of airports Madeira (Madeira and Porto Santo) and 100% of Portway - Handling de Portugal, SA. ANA's share capital was held at 68.56% and 31.44% respectively by 'Parública' by the 'Direcção Geral do Tesouro' [187].

ANA, being an airport manager of recognized competence oriented towards profitability and sustainability, is responsible for management, development and direct operation of eight airports in Portugal [188]. Four of these are located in the continent (Lisbon, Porto, Faro and Beja) and four others in Açores (Ponta Delgada, Stª Maria, Horta e Flores) as Figure 10 illustrates.



Figure 10 - Airports managed by ANA

#### 4.1.1 - ANA and TAP: strategic positioning

The good performance achieved in 2011 by ANA's airports resulted in a growth of 6.7% in terms of number of passengers served, 2% in aircraft movements, 3% of seats offered and 2.4 % in the loading factor [189]. Concerning airlines operating at ANA's airports it is noteworthy Ryanair, which dominated in the ranking of routes with more positive performance (5 out of 10) and whom, alongside with TAP Portugal and Easyjet, accounted for about 65% the traffic at the airports ANA [189]. The market share ranking of the carriers operating in Portugal is illustrated in the following figure.

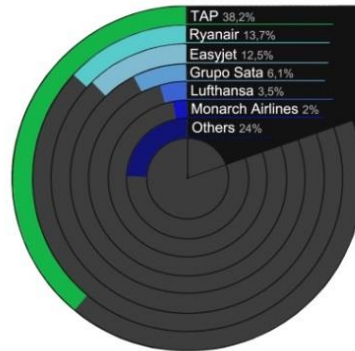


Figure 11 - Market share in Portuguese airports

Of the 10 routes with higher growth in 2011 five have their origin in Portela airport. TAP, responsible for three of these five routes, is the most interested carrier in the construction of the NLA in order to maintain its commitment to strategic positioning using the Portela airport as an international hub. The construction of a new airport in Lisbon aims to reallocate LCC traffic of this new airport, leaving the flag carriers operating in Portela. Two of the three routes mentioned above refer to intercontinental flights (U.S. and Brazil) which reinforce the idea expressed beforehand. The five routes with higher growth in 2011 and originated in Lisbon are displayed in Figure 12.

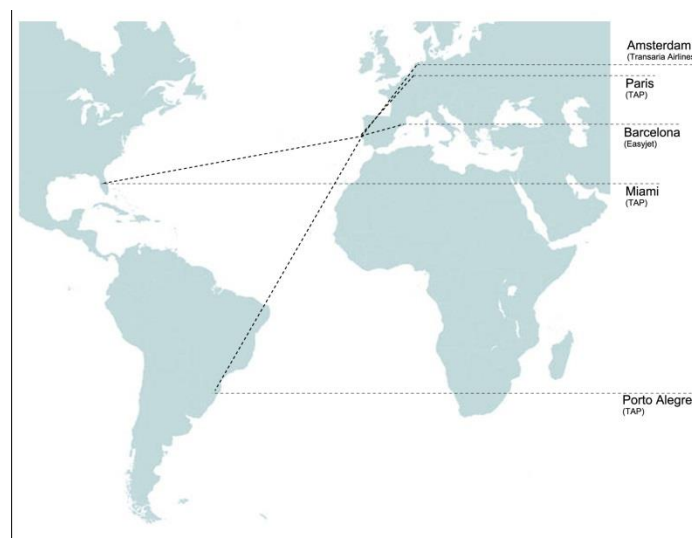


Figure 12 - Routes with higher growth, originating from Portela's airport

The strategic positioning has been carefully planned and implemented by TAP with visible results. In 2011 fifteen new routes were opened at Portela airport. Six of these 15 routes are bound for the American and African continents thus reinforcing the growing wager at Lisbon airport as a hub for transcontinental flights. Figure 13 presents the new routes which opened in Portela airport in 2011.

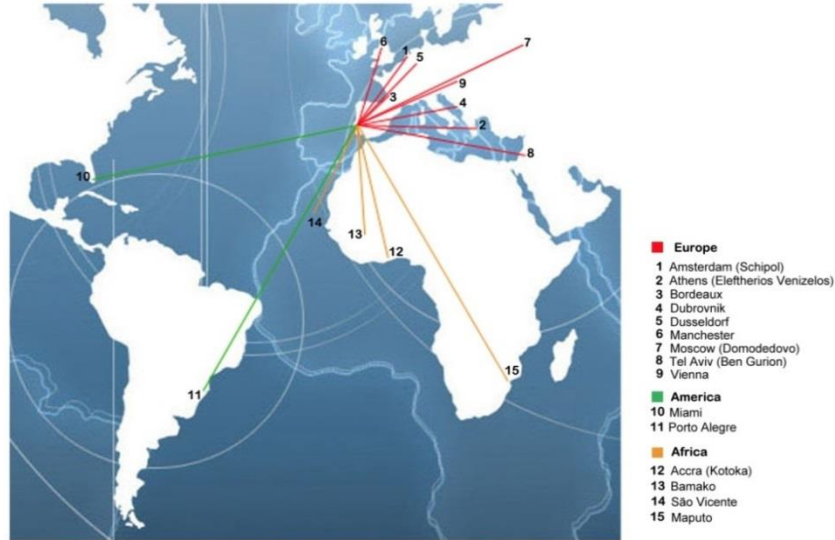


Figure 13 - Strengthening Portela’s airport position as an intercontinental hub

#### 4.1.2 - ANA’s revenue structure

Revenues generated by ANA are divided into: aeronautical revenues (57%), non-aeronautical revenues (around 30%) and airport security as well as assistance for people with reduced mobility (around 13%) – see Figure 14.

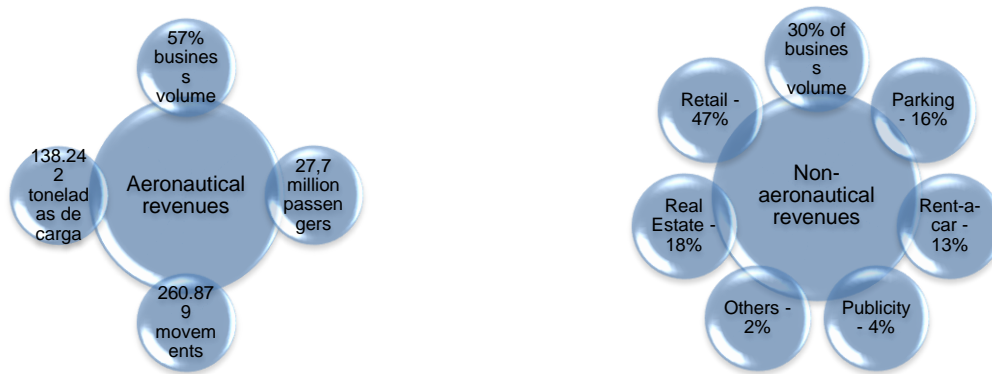


Figure 14 - ANA’s aeronautical and non-aeronautical revenues structure

Despite the 1.4% increase in turnover in the 1st quarter of 2012 compared to 2011 (165,3€ million), the company's net profit fell 12.4% to € 25.3 million due to impairment of debts and reparations on the Faro airport [190].

On April 18th 2012, by resolution adopted by the General Assembly of NAER, SA, it was decided to enter into liquidation of the company with effect from December 31, 2011 [190]. ANA, SA

lives troubled times translated into a 3,6% increase in operational costs in the first semester of 2012 comparing with the homologous period in 2011. Moreover, the net income decreased from 28,9 € to 25.3 million euros due to substantial increase in operational costs and in virtue of the State Budget. The operational results decreased 2.418 thousand euros.

Due to the instability of financial markets the Portuguese government decided to privatize ANA. This model allowed maximizing cash inflow from the sale of the shares that represented the capital of ANA, strengthening competitive position, growth and efficiency of the company for the benefit of the Portuguese civil aviation sector, the national economy and the users of airports managed by ANA. In the 27<sup>th</sup> of December 2012, the Portuguese government privatized ANA to the Vinci group for 3.080 million euros [191].

#### 4.1.3 - The concession contract

On the 14<sup>th</sup> December of 2012, the Portuguese State and ANA signed a Concession contract giving ANA the managerial responsibility over the Portuguese airports located both in continental land and in 'Açores'. The contract relates to the provision of airport services and activities, pursuant to this Concession Agreement [188]. For the purpose of this investigation the contract is relevant since it allows the study of several future options concerning the NLA. Being so, 3 different scenarios will be presented and discussed ahead.

## 4.2 - The Lisbon airport

The Lisbon airport (IATA: LIS, ICAO: LPPT) is the biggest Portuguese airport and also the one with the highest traffic volume. Open to traffic in 1942, with an area of 4,95km<sup>2</sup>, it is divided into 2 runways (since 1962), two civil terminals and a military one (also known as Figo Maduro airport) [192].

Lisbon airport continues to have, year after year, an increase in the number of passengers (Figure 15). From 2010 to 2011, the number of passengers increased 5,1% from 14.066.545 in to 14.790.157 as the number of airport movements increased 2,7% [193] [194]. In Lisbon the increase was 1% concerning the value from 2010 (from 138.147 to 139.497). The main reason for this increase is the higher number of available aircrafts which resulted both in a greater number of seats and, consequently, in a 2% increase in the occupancy rate. Cargo transportation increased 0,5% (93.871 in 2010 to 94.356 tons in 2011).

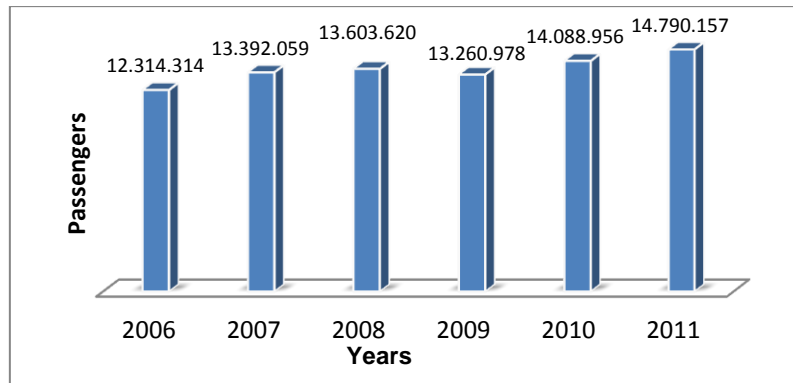


Figure 15 - Passenger evolution in Portela airport 2006-2011.

Sources: [193] [194] [195] [196] [197] [198]

The air traffic growth and the increase in non-aeronautical revenues resulted in an increase in the generated economic value by 4.74% (from 348,2€ million to 364,7€ million). The aeronautical revenues increased 3,9%, the non-aeronautical increased 2,9% and both security and assistance for people with reduced mobility revenues increased 6,2%.

Despite the climate of economic crisis looming in Europe, uncertainty about the permanence of the euro as a single currency, business aviation continues to grow. According to Airports Council International (ACI), the growth in May was 4.8% - 6.1% relative to international traffic and about 2% due to domestic traffic [199].

In the 1st half of 2012 the number of passengers who used the airport of Lisbon grew 3.1%. The evolution of the LCC segment, with a growth of 10.9%, combined with the progress of the offer in terms of movements and an increase in places offered are primarily responsible for this growth [190]. The non-aeronautical revenues grew 2.4% with special weight in retail - 6% increase in revenues. Meanwhile aeronautical revenues grew 1.1%.

Lisbon airport presents itself as an exception to the other airports managed by ANA group since it is the only airport with an increase in the number of passengers in the first two months of 2013 (2.4% in January and 1.4% in February).

### 4.3 - Previous studies on the New Lisbon Airport

Studies of selection for the best location of the NLA date back to 1969, the date of publication of Decree-Law no. 48902 which created the 'Gabinete do Novo Aeroporto de Lisboa' (GNAL) [200]. Later that year, the GNAL presented the opinion of tutelage which emphasize the following points: it was not possible to expand the airport Portela as a solution to consider for the new airport and there is no chance of acceptable location of the new airport on the right bank of the Tagus River.

The geographical relocation of the Lisbon airport began to be studied from 1971 due to future limitations on the use of Portela [10]. Thus, in 1971, two studies clarified the preference for Rio Frio as the location for a new airport infrastructure. The ambition of this project is reflected in the assumption of the construction of 4 parallel runways [200].

The rupture of bonds, due to colonial revolt Carnations (*'Revolução dos Cravos'*) in 1974, triggered a sharp change in the position of Portugal in the world [201]. At the same time, the first oil crisis required an overhaul of global economic growth rates [202]. This theme was on standby for nearly a decade until in 1982 when TAMS/Profabril conducted a comprehensive study encompassing 12 alternative sites for the NLA [203]. It is then that the alternative OTA appears. Located 40 km north of Lisbon, on the right bank of the Tagus, the OTA option put aside the Rio Frio, contrary to previous studies.

The selection process would be reopened in 1990 after Portugal's integration in the EEC. In the same year, ANA EP held a comparative economic study on two possible locations north and south of Lisbon - Ota and Rio Frio. In 1994, another study was developed by ANA, EP considering a third alternative - Montijo. In 1997, by Decree Law n<sup>o</sup> 42/97 of 21 August [204], the Portuguese government established a system of preventive measures for land use in the locations of potential OTA and Rio Frio (since these are viable options at the time). In order to follow up the practical work, 'Novo Aeroporto, S.A.' (NAER) was created in 1998 as part of the work necessary to develop the planning and launching of a new airport in Lisbon.

The selection process ends in 1999. After undertaking economic studies, feasibility studies, operational and preliminary studies of environmental impacts for both possible locations (Rio Frio and OTA), having taken into account a third alternative (adapted for civilian use from Montijo Air Base), the choice fell into OTA. One of the main arguments for this decision was the environmental sensitivity of Rio Frio. In turn, the topographical and hydrological complexities of the venue were drawbacks since they would require the high construction costs, as well as limit the operational flexibility airport [205]. The governmental decision making appeared then in 2005, initiating detailed studies. The table below summarizes the studies conducted between 1969 and 1999 as part of the construction of NAL.

Table 11 - Studies regarding the NLA between 1969 and 1999.

Year	1969	1982	1990	1994	1998/1999		Final Decision	
Entity	GNAL	ANA	ANA	ANA	EPIA	Aéroports de Paris		
Location	Alcochete							
	Fonte da Telha	Fonte da Telha						
	Montijo	Montijo		Montijo A Montijo B				
	Porto Alto	Porto Alto						
	Rio Frio	Rio Frio	Rio Frio	Rio Frio	Rio Frio 08/26 Rio Frio 17/35	Rio Frio 08/26 Rio Frio 17/35		
		Alverca Azambuja Granja Marateca Ota Portela Santa Cruz Tires		Ota	Ota	Ota	Ota	Ota

Sources: adapted from [10] [200] [201] [202] [203] [204] [205]

In March 2007, the Confederation of Portuguese Industry (CIP), dissatisfied with the selected site, sponsored the 'Instituto do Ambiente e Desenvolvimento' (IDAD) and the company 'TIS.pt' to study and identify alternative sites for the construction of the NLA. Three months after the start of the study, IDAD [200] prepared a report that was delivered personally by the Prime Minister [8]. The 'Campo de Tiro de Alcochete' (CTA), military installation, was seen as the best solution.

The impact was such that it took only one week until the Minister of Public Works, Transport and Communications announced the Assembly of the Republic that the decision on the Ota would be suspended and that it would launch a comparative study between Ota and Alcochete. By the 'Despacho de 12 Junho, 2007', the government mandated the 'Laboratório Nacional de Engenharia Civil' (LNEC) to conduct a study in order to compare the alternatives OTA and CTA through a technical analysis. Of the seven critical factors considered, four clearly showed that the CTA option would be a better choice than Ota. Among these four stood the air safety factor that came to be primarily responsible for the final decision taken by the Government - CTA [206].

## 4.4 - The New Lisbon Airport

### 4.4.1 - The new Lisbon airport overview

As foreseen for several decades, the capacity of the Lisbon airport is very limited and will face severe constraints over a near future [8]. Moreover, it is impossible to expand the airport to support a capacity of more than 21 million passengers per year due to urban development in the surrounding areas, so there is a strong possibility that a new airport is required in the short-medium term. In the project for the construction of the NLA, several RO can be identified whereas its value may be appropriate by the project developer through a proper contract design.

The predominant factors for the existence of options in constructing an airport infrastructure are the location and the development plan. The location is crucial since, if appropriate, will enable capturing a possible continuous traffic growth through the expansion of existing infrastructure (expansion option). The NLA could be a Low-cost airport (LCA) that will serve LCC, or it could be a FSA, serving all airlines. This distinction between a LCA and FSA is due to the different needs of LCC and FSC. The latest require air bridges, transit areas, among other commodities that are negligible for LCA, searching for the cheapest, no-frills, solutions. For the purposes of this thesis it is assumed that the NLA will be at the CTA and that the site allows the construction of this infrastructure whose maximum capacity is 40 million passengers / year [200].

In accordance with NAER, this new infrastructure will also allow Portugal to promote its importance as a transcontinental connection hub. This would bring Portugal to the centre of the European air transportation network fostering regional development [8].

#### 4.4.2 - Types of airport considered

To study the different scenarios, two different types of airports were taken into account: Full Service airports (FSA) which serve primarily legacy carriers and LCA intended to serve LCC. This difference will be notorious since one of the motives for the construction of the NLA is that it is targeted to serve the LCC while flag companies will operate at Portela airport. Summing up, regardless of the scenario (flexible or not) the NLA will be a LCA and the Portela airport will work as a FSA.

#### 4.4.3 - Lisbon multi-airport system

The construction of the new airport in Lisbon metropolitan area to serve the LCC will create a MAS in Lisbon - herein referred to as Lisbon MAS. The constituents of this MAS are Lisbon/ Portela and Lisbon/NLA (Figure 16). The first will serve flag companies and the second will serve the LCC. The image below illustrates Lisbon MAS airports location.



Figure 16 - Lisbon MAS.

Source: [68]

The construction of a new airport, targeted to the LCC, will reinforce the position of the Portela airport as a hub for intercontinental flights, by redirecting LCC traffic from Portela to the new airport. TAP argued that the choice for the NLA should enable the company to develop a business strategy for European leadership in Atlantic crossings, either in connection with Brazil or with the Portuguese-speaking African countries (PALOP).

Once NLA will first serve LCC the costs these companies support will be lower than that currently supported in the airport Portela. Therefore, LCC already operating in Lisbon/Portela will be encouraged to increase their turnover as soon as they start operating in Lisbon/NLA. Moreover this opens doors for the entrance of new LCC that hitherto did not operate in Lisbon.

#### 4.4.4 - Phased investment option

The primary scope of this research is to identify and quantify the option of investing in a phased manner. For such end two different constructions of the NLA will be studied: a first one able to withstand the maximum capacity in the opening year (40 million passengers per year) versus a modular construction, with an initial capacity of 10 million passengers per year. Quantifying the option will allow a better comprehension of the RO benefits as well as to perceive the increase of the economic value of the project. Equation (2) will be used to quantify the option value:

$$\text{Phased investment option} = NPV_{flexible\ scenario} - NPV_{inflexible\ scenario} \quad (2)$$

### 4.5 - Scenarios

#### 4.5.1 - Base case scenario

##### 4.5.1.1 - Base case scenario overview

The base case scenario intends to demonstrate the effects of not building a new airport in Lisbon, keeping Portela airport operating. From the year in which its maximum capacity is reached (21 million passengers) the surplus traffic is rejected, and thus redirected to another airport, e.g. Madrid - Barajas airport. The airline companies will not be able to increase the number of flights to and from Lisbon Airport, making the airport Portela longer attractive to those companies. Thus, the impacts of this loss are not only financial but also strategic since it weakens the overall position of the Lisbon airport as a hub for intercontinental flights. Failing to capture the increasing demand of passengers has huge prejudicial consequences to Portugal. This is the most unrealistic scenario.

#### 4.5.1.2 - Revenue flow

In this scenario, the revenue per passenger is deemed regarding the operational results from ANA in 2011, as illustrated by the equation 3 [189]:

$$\text{Revenue per passenger} = \frac{\text{Revenue 2011}}{\text{Passengers 2011}} = \frac{369.194.000}{27.670.795} = 13,34 \frac{\text{€}}{\text{passenger}} \quad (3)$$

#### 4.5.1.3 - Operational costs and investment flows

Similarly to the revenue flow, the cost per passenger was calculated using the operational results from ANA in 2011. The equation below defines the operation costs per passenger:

$$\text{Cost per passenger} = \frac{\text{Operational Costs+Investments 2011}}{\text{Passengers 2011}} = \frac{253.600.000}{27.670.795} = 9,16 \frac{\text{€}}{\text{passenger}} \quad (4)$$

The investments considered in this scenario relate to future expansion of the airport Portela. The investments to be made in 2013 and 2018 are the only ones relevant for the vase case scenario. The amounts are 7 million and 54 million, respectively [207]. These investments will allow the Portela airport to handle 21 million passengers per year as from 2018.

### 4.5.2 - Inflexible scenario

#### 4.5.2.1 - Inflexible scenario overview

In the inflexible scenario the NLA will be operational in 2026, at its maximum capacity of 40 million passengers per year. Yet, it will perform in overcapacity from the year that limit is reached. Figure 17 illustrates this scenario.

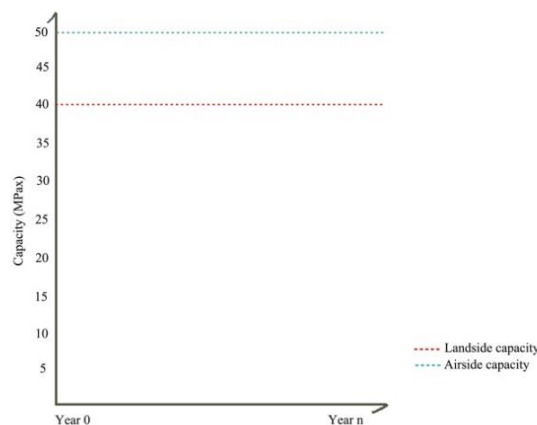


Figure 17 - Levels of airport capacity for the inflexible scenario

#### 4.5.2.2 - Revenue and operational costs flows

For the inflexible scenario, the value considered for the revenue per passenger for the periods between 2011 and 2025 (year prior to the opening of the NLA) was the one obtained in section 4.5.1.1. To achieve the revenue per passenger after 2026 (year when NLA starts operating) for the Portela airport (FSA) and the NLA (this being the LCA) the following procedure was held:

1. Base revenue value: Portela revenue from 2011 – 208.209.000€ [208];
2. Breakup of the number of passengers between FSC and LCC in 2011 to obtain the related market shares (see table 12);

**Table 12 - Passengers in Portela airport by type of carrier and respective market share**

Type of Carrier		Passengers	Market Share (%)
	Full-service	12.213.423	82,58
	Low-cost	2.576.734	17,42
	Total	14.790.157	100

3. Use of the following equations (5) and (6), whereas the ratio of equation (6) was obtained by CEGEA and TRENMO [10] concerning the relation between FSC revenues and LCC revenues;

$$\text{Revenue Portela} = \text{Revenue FSC} * \text{FSC Market Share} + \text{Revenue LCC} * \text{LCC Market Share} \quad (5)$$

$$\text{Revenue FSC} = 1,158 * \text{Revenue LCC} \quad (6)$$

Owing to the fact that ANA does not provide detailed information concerning the ratio between operational costs and revenues, the values used as reference were the ones from CEGEA TRENMO (65% operational costs/revenues ratio for a FSA and 75% operational costs/revenues ratio for a LCA) [10]. The values obtained are displayed in Table 13.

**Table 13 - Passenger related cash flows**

Type of airport		Revenues (€/Pax)	Operational Costs/Revenues	Operational Costs (€/Pax)	Profit (€/Pax)
	FSA	14,42	65%	9,373	5,047
	LCA	12,45	75%	9,315	3,135

To check the coherence of the data, an average EBIT was calculated to compare with the one provided by ANA – 52% [189]. Equation 7 was used for that purpose and the results achieved are displayed in Table 14.

$$\text{Average EBIT} = \frac{\text{EBIT FSC} * \text{Passengers FSC} + \text{EBIT LCC} * \text{Passengers LCC}}{\text{Total Passengers Portela 2011}} = 50,33\% \quad (7)$$

Table 14 - Average EBIT calculation

	EBIT (%)
<b>FSC</b>	53,85
<b>LCC</b>	33,66
<b>Average</b>	50,33

The value obtained is similar to the one provided by ANA. Bearing this, the values obtained are considered as reliable for future calculations. As previously stated, the only variable implied in this model is the number of passengers. Thus being, no economies of scale were considered alongside with the increase of the number of passengers.

#### 4.5.2.3 - Investments flow

The investments considered in this scenario relate, not only to future expansion of the airport Portela (base case scenario), but also to the costs associated with the construction of the NLA. In other words, besides the investments to be made in 2013 and 2018 (7 million and 54 million, respectively) a 15 year loan with an interest rate of 4% was considered. The loan will be paid between 2026 and 2040 assuming a constant interest rate. Equation 8 represents the base value to be paid in the first year without the interest rate.

$$Base\ value = \frac{Total\ investment}{Payment\ period} = \frac{3.600.000.000}{15} = 240.000.000\text{€} \quad (8)$$

#### 4.5.3 - Flexible scenario

##### 4.5.3.1 - Flexible scenario overview

In the flexible scenario the airport is built modularly. The illustration below (Figure 18) shows schematically the evolution of the airport capacity, considering both the terminal and runways. The observation of this graph provides insight on the modular character of the alternative proposed in this investigation - the phased investment option.

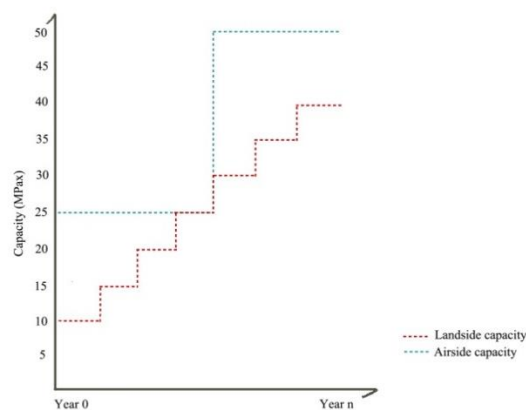


Figure 18 - Levels of airport capacity for the flexible scenario

The airport will start operating with one runway, which accommodates a traffic volume of 25 million passengers per year [10] [45] [46], and a modular terminal which initially withstands 10 million passengers per year. Bearing this, initially, the landside capacity is the limiting factor. A new module capable of receiving 5 million passengers is operational in the year when the traffic demand reaches the modular airport's current maximum capacity. When the demand reaches 25 million, apart from adding a new landside module, the second runway starts operating.

#### 4.5.3.2 - Revenue and operational costs flows

The revenues and operating costs considered in this scenario are similar to those obtained in section 4.5.2.1. The main difference relates to the freedom of the model to calculate the opening year of the NLA (2026 in the inflexible scenario) and the year of commencement of operation of each module and the second runway. These issues will be addressed in Chapter 5.

#### 4.5.3.3 - Investments flow

The cost structure used in this research follows the report CEGEA and TRENMO [10]. The two tracks represent 21,16% of the total cost of the NLA while the remaining 78,84% concern:

- Terminals, luggage processing facilities, offices and air conditioned;
- Technical equipment (e.g. control tower);
- Taxiways, slots for planes to park and other airside facilities; and
- Other infrastructure, equipment and technology needed so the airport operates properly.

Accordingly, the modular airport costs are displayed in Table 15.

**Table 15 - Modular airport costs**

	<b>Costs (Million euros)</b>
<b>Initial 10 million passengers module</b>	709,6
<b>Runway</b>	380,9
<b>5 million passengers module</b>	354,8

In addition to the investments to be made in 2013 and 2018 (7 million and 54 million, respectively – as in the other two scenarios), several loans were considered regarding the necessary investments throughout the study period. Table 16 displays not only the loan periods, but also the periods during which the loans are paid. Again, a constant interest rate (4%) was assumed.

**Table 16 - NLA investment structure**

<b>Loan application year</b>	<b>Loan value (Thousand euros)</b>	<b>Payment period</b>
2026	1.090.444	2026-2033
2035	354778	2035-2036
2042	354778	2042-2043
2047	735665	2047-2050
2051	354778	2051-2052
2054	354778	2054-2055
2056	354778	2056-2057

For the scope of this research and since the airport is initially being planned as a modular one, during the expansion processes, the construction of these modules and of the 2<sup>nd</sup> runway will not interfere with the normal operation of the NLA.

The ability to adjust the terminal continuously gives flexibility to the project whilst at the same time accommodates the demand, increasing the value of the project. Accordingly, modularity proves to be a major factor in the addition of value to the project, as it allows dealing with the passenger traffic evolution uncertainty.

In addition to the difference in investment and, comparing with the inflexible scenario, this modular airport requires less time to become operational. The location of Alcochete enables the deployment of this type of airport mainly due to reduced costs of site preparation that allow the rapid realization of the investment [200]. The only limiting factor is the undertaking of the necessary studies.

# THE REAL OPTIONS MODEL

## 5.1 - The real options model overview

As referred in Chapter 3, RO analysis derives from FO. Their application to 'real' assets is not straightforward. The most relevant proxy needed to be found in this case is volatility [2]. In FO, volatility ( $\sigma$ ) is given by the normal market fluctuation prices. To study the NLA the volatility will be the standard deviation from LCC passengers' demand from 2008 until 2012 in six different European airports.

The real options model combines an increase factor,  $\mu$ , and a decrease factor,  $d$ . Those were determined resorting to equations (9) and (10) following Cox *et al.* to model in discrete time [176]:

$$\mu = e^{\sigma\sqrt{\Delta t}} \quad (9)$$

$$d = \frac{1}{\mu} = e^{-\sigma\sqrt{\Delta t}} \quad (10)$$

As  $\Delta t$  is the (one year) time interval and volatility the standard deviation from the average volatility both for FSC and LCC.

For every possible scenario, at each node, the probability that influences the final evaluation of the project must be calculated. The probability of each outcome can be determined in this model, being  $p$  the probability increase factor, and  $(1 - p)$  the probability decrease factor [209] (11):

$$p = \frac{1}{2} + \frac{1}{2} * \left(\frac{v}{\sigma}\right) * \sqrt{(\Delta t)} \quad (11)$$

The model implementation in section 5.2 will allow a better comprehension of its steps.

## 5.2 - Traffic development

The assumptions regarding the demand forecast for FSC are based on historic evolution from 2009 until 2011 from Portela Airport while the demand for LCC is based on calculations concerning 6 different airports as Table 17 illustrates. These airports have been selected because of their characteristics (Portela for being the aim of the case study, Francisco Sá Carneiro and Luton for being LCAs, and Madrid - Barajas and Barcelona - El Prat because they can accommodate Portela's

exceeding traffic if the NLA is not built) and the limited information provided by airport owning companies.

**Table 17 - LCC growth rate and volatility data.**

Airport	Time period (Years)	Average growth rate LCC (%)	Average volatility LCC (%)
Portela	2009-2011	7,17	3,08
Francisco Sá Carneiro	2008-2011	27,35	26,52
Barcelona – El Prat	2009-2012	51,05	27,25
Madrid – Barajas	2009-2012	13,72	12,11
London/Luton	2008-2011	-3,74	6,36
Schipol	2009-2012	11,64	11,26
Average		17,87	9,3

Sources: [193] [194] [198] [210] [211] [212] [213] [214] [215] [216] [217] [218]

Option theory can only be applied after the annual average growth rate and volatility have been estimated. The average growth rate over the last 5 years is 3,81% while the volatility is 5,17%. The non-linear pattern over the last 5 years explains the high volatility. Furthermore it was assumed that the NLA will start operating early in the year when demand reaches or passes the 21 million passengers.

These assumptions resulted in the input data presented in Table 18, which was used to calculate traffic growth throughout the 50 year period.

**Table 18 - Input data on demand growth**

	FSC	LCC	Units
<b>Initial passenger demand</b>	12.213.423	2.576.734	Passengers
<b>Volatility (<math>\sigma</math>)</b>	4,11	9,3	%
<b>Increase factor, <math>\mu</math></b>	1,042	1,098	
<b>Decrease factor, <math>d</math></b>	0,96	0,91	
<b>Probability (<math>p</math>)</b>	0,653	0,793	%

The NLA model requires data on the expected development of passengers demand allowing populating a table of possible traffic levels over the 50 year period of interest. The demand evolution over the 50 years period was calculated using: initial passenger demand for both FSC and LCC, the increase and decrease factors described in section 5.1, volatility, growth rate and the associated probability – see tables 17 and 18.

Each of the Binomial trees produced  $2^{50}$  possible events for both the FSC and LCC traffic development – see figures 19 and 20.

2011	2012	2013	2014	2015	2016	2017	2018	2019	...	2058	2059	2060
Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 47	Period 48	Period 49	Period 50
2.576,2	2.827,6	3.103,5	3.406,3	3.738,7	4.103,5	4.503,8	4.943,3	5.425,6	186593	204799	224781	246714
	2.347,2	2.576,2	2.827,6	3.103,5	3.406,3	3.738,7	4.103,5	4.503,8	154892	170005	186593	204799
		2.138,6	2.347,2	2.576,2	2.827,6	3.103,5	3.406,3	3.738,7	128577	141123	154892	170005
			1.948,4	2.138,6	2.347,2	2.576,2	2.827,6	3.103,5	106733	117147	128577	141123
				1.775,2	1.948,4	2.138,6	2.347,2	2.576,2	88599,7	97244,5	106733	117147
					1.617,4	1.775,2	1.948,4	2.138,6	73547,3	80723,4	88599,7	97244,5
						1.473,6	1.617,4	1.775,2	61052,2	67009,1	73547,3	80723,4
							1.342,6	1.473,6	50679,9	55624,8	61052,2	67009,1
								1.223,3	42069,7	46174,5	50679,9	55624,8
									34922,4	38329,8	42069,7	46174,5
									28989,4	31817,9	34922,4	38329,8
									24064,3	26412,3	28989,4	31817,9
									19975,9	21925	24064,3	26412,3
									16582,2	18200,1	19975,9	21925
									13765	15108,1	16582,2	18200,1
									11426,4	12541,3	13765	15108,1
									9485,16	10410,6	11426,4	12541,3
									7873,7	8641,95	9485,16	10410,6
									6536,02	7173,75	7873,7	8641,95
									5425,6	5954,98	6536,02	7173,75
									4503,83	4943,28	5425,6	5954,98
									3738,67	4103,45	4503,83	4943,28
									...	...	...	...

Figure 19 – Traffic demand tree FSC

2011	2012	2013	2014	2015	2016	2017	2018	2019	...	2058	2059	2060
Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	...	Period 48	Period 49	Period 50
12.213	12726,4	13260,8	13817,8	14398,1	15002,8	15632,9	16289,4	16973,5	81042,7	84446,3	87992,9	91688,4
	11721,2	12213,4	12726,4	13260,8	13817,8	14398,1	15002,8	15632,9	74641,4	77776,2	81042,7	84446,3
		11248,7	11721,2	12213,4	12726,4	13260,8	13817,8	14398,1	68745,8	71633,0	74641,4	77776,2
			10795,4	11248,7	11721,2	12213,4	12726,4	13260,8	63315,8	65975,0	68745,8	71633,0
				10360,2	10795,4	11248,7	11721,2	12213,4	58314,8	60763,9	63315,8	65975,0
					9942,67	10360,2	10795,4	11248,7	53708,7	55964,4	58314,8	60763,9
						9541,93	9942,67	10360,2	49466,5	51544,0	53708,7	55964,4
							9157,34	9541,93	45559,3	47472,7	49466,5	51544,0
								8788,25	41960,8	43723,1	45559,3	47472,7
									38646,5	40269,5	41960,8	43723,1
									35593,9	37088,8	38646,5	40269,5
									32782,5	34159,3	35593,9	37088,8
									30193,2	31461,2	32782,5	34159,3
									27808,3	28976,2	30193,2	31461,2
									25611,9	26687,5	27808,3	28976,2
									23588,9	24579,6	25611,9	26687,5
									21725,7	22638,1	23588,9	24579,6
									20009,7	20850,0	21725,7	22638,1
									18429,2	19203,2	20009,7	20850,0
									16973,5	17686,4	18429,2	19203,2
									15632,9	16289,4	16973,5	17686,4
									14398,1	15002,8	15632,9	16289,4
									...	...	...	...

Figure 20 – Traffic demand tree LCC

For every node, there is a probability (p) associated. This probability varies accordingly with the type of traffic, as shown in figures 21 and 22.

2011	2012	2013	2014	2015	2016	2017	2018	2019	...	2058	2059	2060
Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	...	Period 48	Period 49	Period 50
1	0,65338	0,4269	0,27893	0,18225	0,11908	0,0778	0,05083	0,03321	3,1E-09	2,1E-09	1,3E-09	8,8E-10
	0,34662	0,45295	0,44392	0,38673	0,31585	0,24765	0,18878	0,14096	7,7E-08	5,1E-08	3,4E-08	2,3E-08
		0,12015	0,2355	0,30774	0,33512	0,32844	0,30044	0,26173	9,2E-07	6,3E-07	4,3E-07	2,9E-07
			0,04164	0,10884	0,17778	0,23232	0,26564	0,2777	7,1E-06	5,0E-06	3,5E-06	2,4E-06
				0,01443	0,04716	0,09244	0,14092	0,18415	4,1E-05	2,9E-05	2,1E-05	1,5E-05
					0,005	0,01961	0,04486	0,07815	1,8E-04	1,3E-04	9,7E-05	7,0E-05
						0,00173	0,00793	0,02073	6,6E-04	4,9E-04	3,7E-04	2,7E-04
							0,0006	0,00314	2,0E-03	1,5E-03	1,2E-03	8,9E-04
								0,00021	5,1E-03	4,1E-03	3,2E-03	2,5E-03
									1,2E-02	9,3E-03	7,5E-03	6,0E-03
									2,3E-02	1,9E-02	1,6E-02	1,3E-02
									3,9E-02	3,4E-02	2,8E-02	2,4E-02
									6,1E-02	5,3E-02	4,6E-02	4,0E-02
									8,4E-02	7,6E-02	6,8E-02	6,1E-02
									1,1E-01	9,8E-02	9,1E-02	8,3E-02
									1,2E-01	1,1E-01	1,1E-01	1,0E-01
									1,2E-01	1,2E-01	1,2E-01	1,2E-01
									1,1E-01	1,2E-01	1,2E-01	1,2E-01
									9,8E-02	1,0E-01	1,1E-01	1,1E-01
									7,7E-02	8,4E-02	9,1E-02	9,7E-02
									5,5E-02	6,3E-02	7,0E-02	7,7E-02
									3,6E-02	4,3E-02	5,0E-02	5,7E-02
									2,2E-02	2,7E-02	3,2E-02	3,8E-02
									1,2E-02	1,5E-02	1,9E-02	2,4E-02
									6,1E-03	8,2E-03	1,1E-02	1,4E-02

Figure 21 – Probability tree FSC

2011	2012	2013	2014	2015	2016	2017	2018	2019	...	2058	2059	2060
Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	...	Period 48	Period 49	Period 50
1	0,79278	0,6285	0,49826	0,39501	0,31315	0,24826	0,19682	0,15603	2,3E-05	1,8E-05	1,4E-05	1,1E-05
	0,20722	0,32856	0,39072	0,413	0,40927	0,38935	0,36012	0,32628	0,00028	0,00022	0,00018	0,00015
		0,04294	0,10213	0,16193	0,21396	0,25443	0,28239	0,2985	0,00162	0,00134	0,00111	0,00092
			0,0089	0,02822	0,05593	0,08867	0,12302	0,15605	0,00622	0,00527	0,00446	0,00376
				0,00184	0,00731	0,01738	0,03216	0,05099	0,01749	0,01516	0,01311	0,01131
					0,00038	0,00182	0,00504	0,01066	0,0384	0,03407	0,03015	0,02662
							7,9E-05	0,00044	0,00139	0,06859	0,06234	0,05648
								1,6E-05	0,0001	0,10245	0,09543	0,08858
										0,13055	0,12473	0,11866
											0,11242	0,11242
										0,14408	0,14128	0,13785
											0,13387	0,13387
										0,13934	0,14033	0,14052
											0,13997	0,13997
										0,1192	0,12338	0,12689
										0,09088	0,09675	0,10226
											0,10737	0,10737
										0,06213	0,06808	0,07402
											0,07988	0,07988
										0,03828	0,04322	0,04837
											0,05369	0,05369
										0,02134	0,02485	0,02866
											0,03274	0,03274
										0,01081	0,01299	0,01545
											0,01819	0,01819
										0,00499	0,00619	0,0076
											0,00923	0,00923
										0,0021	0,0027	0,00342
											0,00429	0,00429
										0,00081	0,00108	0,00141
											0,00183	0,00183
										0,00029	0,00039	0,00054
											0,00072	0,00072
										9,2E-05	0,00013	0,00019
											0,00026	0,00026

Figure 22 – Probability tree LCC

Being so, each of the results provided by the traffic demand Binomial trees will be multiplied by the respective probability. The combination of the values obtained will provide the traffic demand by type of carrier per year. Figures 23 and 24 illustrate the annual traffic demand for both FSC and LCC.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	...	2058	2059	2060
	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	...	Period 48	Period 49	Period 50
Total Passengers FSC	12213	12378	12545	12714	12885	13058	13234	13413	13593	...	22906	23215	23527

Figure 23 – Traffic per year FSC

	2011	2012	2013	2014	2015	2016	2017	2018	2019	...	2058	2059	2060
	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	...	Period 48	Period 49	Period 50
Total Passengers LCC	2576	2728	2889	3059	3239	3430	3632	3846	4073	...	37998	40238	42609

Figure 24 – Traffic per year Lcc

The cost per passenger was here considered to obtain the operation costs for both Portela and NLA. The expected passengers per year, the revenues and operation costs will then be calculated multiplying the respective binomial tree by the probability binomial tree.

## 5.3 - Net Present Value

### 5.3.1 - Formulation

To assess the value of a project in current money is recurring practice to use the NPV. The NPV represents the sum of present and future cash flows (which are assumed to be static and predetermined throughout the life span of the project) adjusted to the present value, deducted from the investment initially made (see equation 12). It is common for large a negative cash flow to appear at the beginning of the project (t = 0) since the investment is made at that moment. This is the most used investment valuation method, despite its failure to recognize managerial flexibility [219]. The selection

of the appropriate discount rates assumes an important role since it should, at least, equal the rate of return of equivalent investment alternatives in the capital market.

$$NPV = C_0 + \sum_{t=0}^n \frac{C_t}{(1+r)^t} \quad (12)$$

Where,

$C_0$ : cash flow at time zero (can be considered as the initial investment);

$C_t$ : cash flow at time  $t$ ;

$r$ : discount rate;

$n$ : project lifespan.

The NPV is estimated after it has been discounted by an appropriate discount rate (usually risk-free rate) which will reduce the value of the cash flow to present value terms. The correct selection of which cash flows should be used in NPV valuation is crucial – only the incremental ones such as opportunity costs and side effects must be considered.

### 5.3.2 - Weighted average cost of capital

Selecting a benchmark that is comparable across both firms and sectors to which the risk measures will be applied is the first to take before even measuring risk [220]. Companies, which use both equity and debt, tend to estimate the discount rate using WACC. This alternative to measure the cost of capital represents the weighted average of the returns required by providers of debt and equity finance to a company [45]<sup>35</sup>. WACC can be estimated using the following equation 13.

$$WACC = k_E * \frac{E}{(D+E)} + k_D * (1 - t) * \frac{D}{(D+E)} \quad (13)$$

Where,

$k_E$ : cost of equity;

$k_D$ : cost of debt (before tax);

$t$ : corporate tax;

$\frac{E}{(D+E)}$ : weight of the equity in the capital structure;

$\frac{D}{(D+E)}$ : weight of debt in the capital structure.

### 5.3.3 - Cost of debt and cost of equity

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<sup>35</sup> The cost of capital is the most common benchmark used in developed countries by companies and regulators.

The cost of debt ( $k_D$ ) is measured as the risk-free rate,  $r_f$ , plus a debt premium over the rate [220]<sup>36</sup>. On the other hand, the cost of equity,  $k_E$ , can be estimated using Capital Asset Pricing Model (CAPM). The cost of debt concerns the rate of return a shareholder requires on an equity investments. In other words it is the rate of return the shareholder could have earned if he put the same amount of money in a different investment with the same risk. CAPM is the most widely used model to obtain the cost of equity mostly due to its mathematical simplicity [45]. The cost of equity was obtained resorting to equation 14.

$$k_E = r_F + \beta_A * (r_M - r_F) \quad (14)$$

Where,

BA: asset beta;

$(r_m - r_f)$ : market risk premium<sup>37</sup>.

A positive NPV – a positive result of the total payoff before being discounted for both time value of money and risk - points out that the investment should be taken along. On the other hand, when NPV is close to zero, investors tend to hesitate in making a decision (either invest or reject a project).

## 5.4 - Sensitivity analysis

After estimating the relevant NPVs for the various scenarios, a sensitivity analysis will be carried out in order to estimate how changing the most relevant input variables affects the final results. The sensitivity analysis will be carried out concerning the inflexible and flexible scenarios.

Since the volatility of FSC and LCC is the most important variable modelled, the sensitivity analysis was performed by varying the respective value. Given that there are two volatilities applied in the model (one for FSC and another for LCC), each one were varied individually holding the other constant. The second most important factor is the investment costs. Thus being, a second sensitivity analysis will be performed changing this variable's value by +/- 25% as shown in equations 15 and 16.

$$NPV = \frac{NPV_{investment\ costs+25\%} - NPV_{investment\ costs}}{NPV_{investment\ costs}} \quad (15)$$

$$NPV = \frac{NPV_{investment\ costs-25\%} - NPV_{investment\ costs}}{NPV_{investment\ costs}} \quad (16)$$

<sup>36</sup> The premium can be measured in two distinct ways: either directly from the yield of a company's bond or through comparator information.

<sup>37</sup> Instead of investing in risk-free assets sometimes investors hold risky securities. The market risk premium represents their expectation when holding these risky assets over investing in risk-free assets.

## 5.5 - Results

### 5.5.1 - Financial parameters

For the correct application of the model and in order to get the NPV in different scenarios, it was first of all necessary to determine the financial parameters described in section 5.3. The results obtained are displayed in Table 19.

**Table 19 - Financial parameters outcome**

Variable	Outcome
<b><math>k_E</math>: cost of equity</b>	5,03%
<b>WACC: Weighted average cost of capital</b>	5,25%

### 5.5.2 - Scenarios

By implementing the constraints, assumptions, and input data introduced in previous sections onto the Binomial lattice model it was possible to dynamically forecast the passenger traffic. This model allowed the estimation of a range of possible passenger traffic for each one of the 50 years period alongside with the probabilities associated with each forecast.

Concerning only the flexible and inflexible scenarios and based on the volatility and growth rate of FS carriers and LCC calculated in section 5.2 and implemented in the NLA model, the NLA will become operational in 2026. The main differences between these two scenarios as well as the results from the base case scenario will be presented and discussed ahead.

#### 5.5.2.1 - Base case scenario

The base case scenario produced the highest NPV's. However, the values obtained are not credible. Table 20 presents the NPV for the base case with a 10-year time interval.

**Table 20 - NPV base case**

NPV	Thousand €
10 years	452.184
20 years	836.501
30 years	1.077.020
40 years	1.221.208
50 years	1.307.646

The NPV obtained is fairly high as it is considered that the NLA will not be built and the Portela airport will continue to operate at maximum capacity. This scenario is highly unrealistic since if a new airport is not built to deal with the traffic surplus, companies will move from Portela airport to airports like Madrid – Barajas or Barcelona – El Prat as these allow carriers continued growth while providing them with suitable facilities. Literature has shown that the lack of infrastructure and ability to expand has caused many airlines have changed their place of operations to other airports [52] [91] [92].

Furthermore, the negative externalities derived from the lack of investment will critically affect the future traffic in Portela airport.

Once the Portela airport will reach the capacity limit in 2026, it was assumed it would operate within its capacity limit during the remaining 34 years of the study period. This is the explanation of obtaining such high values for a scenario that would actually produce numerous losses for airlines, ANA and hence for Portugal. Of the three scenarios considered in this investigation, this deserves less focus since not constructing the NLA would produce contradictory results to those obtained by the model.

#### 5.5.2.2 - Inflexible scenario

The NPV in the inflexible scenario is much lower than the one from base case since a huge investment is made. The impact of the investment is strongly reflected in the NPV as illustrated in Table 21.

**Table 21 - NPV inflexible case**

NPV	Thousand €
10 years	516.790
20 years	308.927
30 years	-484.558
40 years	-343.894
50 years	-236.197

The NPV between 10 and 20 years suffers a significant descent due to the investments in the NLA, which begin in 2026 and go on until 2030 for the NPV at 20 years. Nevertheless, the impact is felt much more sharply in the NPV at 30 years, as it considers the 15 years for the payment of the airport. Up to the end of the period considered in the research the NPV rises as expected, since no more investments are made.

#### 5.5.2.3 - Flexible scenario

The flexible scenario is the most important component of the entire investigation as the results emphasize the value of incorporating flexibility in planning the NLA. The NPV obtained for this scenario is shown in Table 22.

**Table 22 - NPV flexible case**

NPV	Thousand €
10 years	516.790
20 years	583.177
30 years	570.507
40 years	591.938
50 years	637.905

By analysing in detail the results obtained, this value is readily apparent. Thus, by itself, the NPV obtained is reason enough to consider incorporating flexibility in planning the NLA. The NPV at 10 years is equal to that of the other scenarios since no investment is made in this period. The investments are spread throughout the study time period accordingly with Table 16 (section 4.5.3.2) which allows perceiving the key differences between the flexible and the inflexible scenarios, as well as their impact.

Accordingly with the growth rates and traffic volatility calculated, the NLA will start operating in 2026 (alike in the inflexible scenario). Figure 25 enables a better understanding of the main differences regarding these two scenarios.

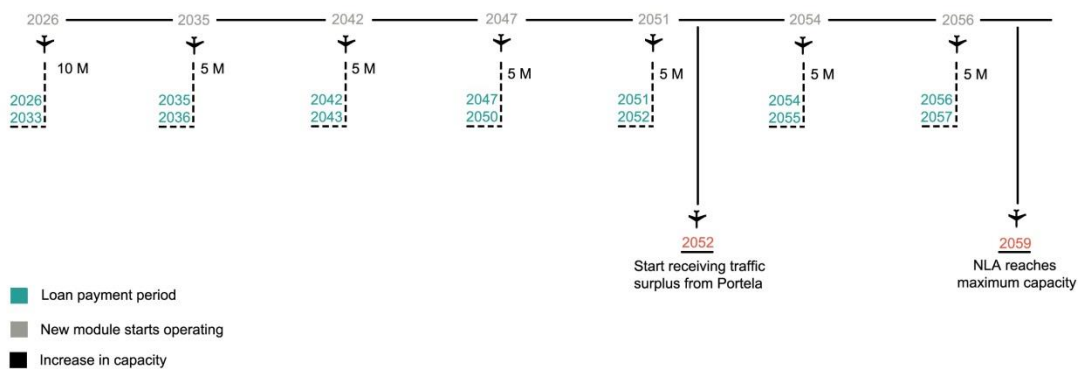


Figure 25 - Modular airport relevant data

The first major difference between this scenario and the inflexible scenario is the initial capacity of the NLA. With a module capable of supporting 10 million passengers per year (40 million in scenario inflexible) and with only one runway in operation (instead of two), it is possible to serve the LCC traffic for several years reducing the first loan amount and, therefore, its payment period (1.090.444 vs. 3.600.000 thousand euros and 8 instead of 15 years). Modules capable of supporting an additional capacity of 5 million passengers per year are added so that the airport follows the traffic evolution modelled (2035, 2042, 2047, 2051, 2054 and 2056).

In addition to the module that allows supporting an additional capacity of 5 million passengers per year, in 2041 the second runway goes into operation since the traffic in that year exceeds the 25 million passengers per year. The investment impact is reflected in the NPV at 40 years whereas in 10 years (30 to 40 years) it increases only 21.431 million euros. In the final two years of the study period it is assumed that the NLA will operate at full capacity (40 million passengers per year).

**Making the most of the real options model**

The flexible scenario is the scenario that allows taking advantage of the implemented model. Depending on the volatility and growth rates defined for the LCC and FSC, and due to the modularity

of the airport, the model calculates: the opening year of the NLA, the years in which the 5 million passenger per year modules must be operational, the year in which the second runway should be operational and all costs as well as loans and payment periods associated with each construction. If the volatility and growth rates are sufficient so the total traffic in the NLA exceeds the 35 million passengers per year, all of the 6 modules will be constructed. On the other hand, if the traffic grows at a less pronounced rate, the model will only invest in a certain number of modules enough to withstand the necessary traffic.

### 5.5.3 - Option value

To determine the value of the hypothesis presented in the investigation (phased investment option) only the flexible and inflexible scenarios were considered. The base case scenario was excluded since the values obtained do not represent what would happen in reality, as explained in section 5.4.2.1.

Equation 2 (section 4.4.4) was used to calculate the value of the phased investment option, thereby obtaining the value of the flexibility introduced into the model of the NLA. Table 23 illustrates the values of the option under study concerning 10-year time intervals.

**Table 23 - Phased investment option value**

<b>NPV</b>	<b>Inflexible scenario (thousand euros)</b>	<b>Flexible scenario (thousand euros)</b>	<b>Option value (thousand euros)</b>
10 years	516.790	516.790	0
20 years	308.927	583.177	274.250
30 years	-484.558	570.507	1.055.065
40 years	-343.894	591.938	935.832
50 years	-236.197	637.905	874.102

The NPV in the first 10 year interval is the same as no investments are made until 2026. The 91.106 thousand euros difference in the NPV at 20 years results from the difference in value of the loans payment (3.600.000 in the inflexible scenario against 1.090.444 thousand euros in the flexible scenario). The value of the latent option is thus observable mostly in the NPV at 30 years as it accounts for the entire payment of the loan in the inflexible scenario. By itself, this explains such a negative result. The results shown in Table 23 highlights that the option to wait before investing huge financial resources in an over scaled airport is reasonable, at least in economic terms. The same conclusions were reached by Chambers and Neiva [45] [46].

### 5.5.4 - Sensitivity analysis results

#### ***Volatility***

The first sensitivity was made regarding both the FSC and the LCC volatilities. Tables 24 and 25 present the result of this sensitivity analysis.

**Table 24 - Sensitivity analysis: volatility FSC**

Volatility FSC (%)	NPV (Thousand euros)	
	Flexible	Inflexible
4,11	637.905	-236.197
5	664.144	-219.907
10	632.055	-135.117
15	534.911	-50.106
20	485.865	40.153
25	462.391	124.350
30	504.450	199.262

In the inflexible scenario the NPV increases alongside the volatility increase of the FSC. That is supposed to occur once the investment is made in a fixed time interval (2026-2040).

Regarding the flexible scenario the NPV decreases with the increase in volatility. The explanation for this effect is related to the anticipation of the investments which increase their impact on the NPV. To aid in the perception of this effect serves as an example the increase from 20 to 25% in the FSC's volatility. By itself, this 5% increase in the volatility makes the construction of the NLA starts one years before (from 2019 to 2018) thus reducing the NPV.

**Table 25 - Sensitivity analysis: growth rate LCC**

Volatility LCC (%)	NPV (Thousand euros)	
	Flexible	Inflexible
5	896.194	-279.449
9,3	637.905	-236.197
10	634.974	-228.622
15	513.289	-166.623
20	402.337	-94.285
25	278.752	-26.502
30	234.280	34.278

As in the previous sensitivity analysis, the NPV in the inflexible scenario increases alongside the volatility increase of the LCC. Once the investment is made in a fixed time interval (2026-2040) this outcome is expected.

The more controversial results are the ones obtained for the flexible scenario. Even though, at first hand, these results may seem hard to explain, the reason is the same given in the previous sensitivity analysis with the addition that the traffic from LCC is directly connected with the NLA. Thus, the increase in the LCC traffic requires an anticipation of investment greater than the one in the previous sensitivity analysis. These results are reflected in the NPV, which decreases with the increase in the volatility. However, opting for a modular construction continues to be a better solution regardless of the volatility. One must understand that, since the estimated value for the volatility is 9,3%, is not reasonable to think that it will change to values such as 25% and 30% as presented in the sensitivity analysis.

### **Investment costs**

The other sensitivity analysis performed examined a variation of +/- 25% in the costs associated with the construction of the NLA. Tables 26 and 27 display the costs used in the sensitivity

analysis (accounting for both the inflexible and flexible scenarios), while Table 28 displays the results obtained.

**Table 26 - Inflexible scenario costs**

	Costs (Million euros)	Costs +25%	Costs -25%
Investment	3.600	4.500	2.700

**Table 27 - Modular airport costs**

	Costs (Million euros)	Costs +25%	Costs -25%
Initial 10 million passengers module	709,6	886.945	532.167
Runway	380,9	476.109	285.665
5 million passengers module	354,8	443.473	266.084

**Table 28 - Sensitivity analysis to airport investment costs**

	Costs +25%	Costs -25%	$\Delta$ NPV (%)
Inflexible scenario	-616.342	144.001	+/-160,97
Flexible scenario	693.287	859.208	+/-34,68

By observing Table 28, it is clear that the variation in costs has a much greater impact on the inflexible scenario than in the flexible one. This is mainly due to the fact that the entire investment starts being made in the 16<sup>th</sup> year of the study period (between 2026 and 2040) and since it is made in the early years of the project it has a greater impact on the NPV. On the other hand, in the flexible scenario, and since the investments are spread throughout the study period, their variation do not affect that much the NPV. Once again, the choice of a flexible scenario (designed through a phased investment option) presents itself as the best investment solution.

### 5.5.5 - Monte Carlo simulation

Resorting to MCS and through computing 5000 simulations the inflexible and flexible scenarios NPV were obtained with their respective probability (and frequency) distribution.

The use of MCS aims at achieving an approximate likelihood (not exact) for the NPV in each scenario. Therefore, and due to the complex nature of the variables used, it is necessary to bear in mind certain assumptions.

#### 5.5.5.1 - Distributions

##### **Growth rates**

For these two variables a normal distribution was assumed. The mean value is the deterministic value used in previous valuations (Table 18, section 5.2) while the standard deviation assumed was 10% of that value<sup>38</sup>.

<sup>38</sup> The graphics with the distributions implemented in the RO model can be found in Annex 3 alongside with a brief description.

### **Volatilities**

Just life for the growth rates, the mean value used was the one obtained in Table 18, while the standard deviation assumed was 10% of that value. These distributions are presented in Annex 3.

### **Investments**

It is common knowledge that the costs associated to every project will most likely be higher than the expected value. Bearing this, in the MCS, a truncated normal distribution was defined for every investment cost considering that, in the best scenario, the minimum value of the cost would be 87,5% of the original value.

#### 5.5.5.2 - Inflexible scenario

The investment made in this scenario is the payment of the 3.600 million euros loan through 15 periods with a constant growth rate of 4%. The minimum value was defined as 210.000 thousand euros as reflected in Figure 26.

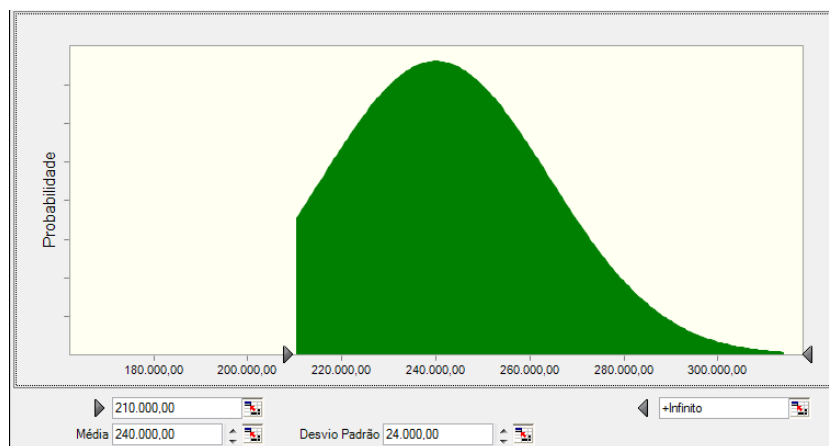


Figure 196 - Truncated normal distribution for the inflexible scenario's loan value

#### 5.5.5.3 - Flexible scenario

In this scenario different investments are made throughout the study period, each with their own value. Alike in the inflexible scenario, the investments follow a truncated normal distribution. The three different investments values (loan amounts), normal truncated distributions can be found in Annex 3.

5.5.5.4 – Results

As with the remaining NPV's obtained throughout this study, once again the value of resorting to flexibility must be highlighted. Figures 27 and 28 show the NPV of the inflexible and flexible scenarios obtained using MCS software Crystal Ball.

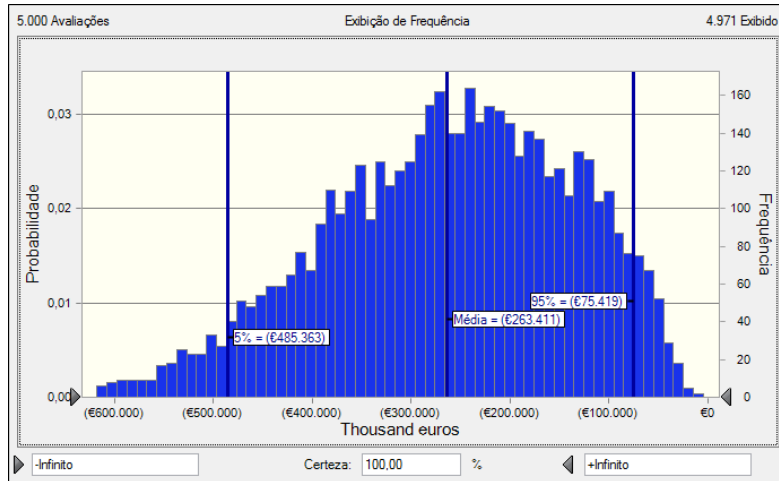


Figure 27 - MCS NPV for the inflexible scenario

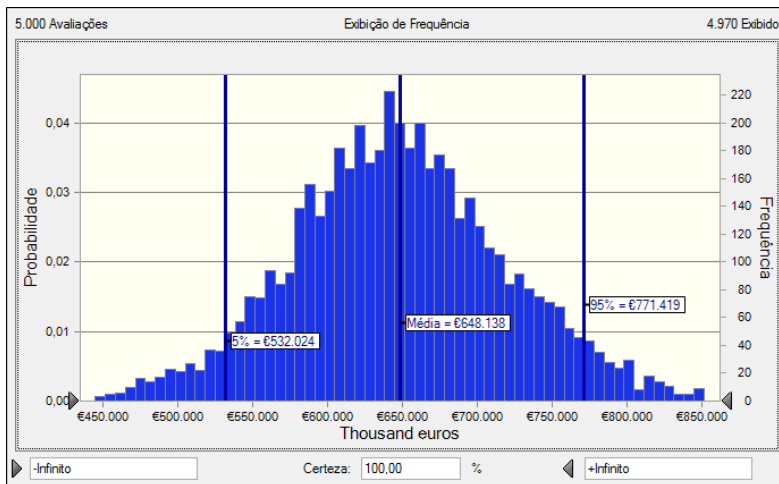


Figure 208 - MCS NPV for the flexible scenario

By observing both figures, one may conclude that the use of MCS had no significant effect on the final results, thereby demonstrating the reliability of the RO model implemented. As Figures 27 and 28 illustrate, the NPV obtained for the flexible scenario exceeds the one from the inflexible scenario in over 800 million euros (648.138+263.411). Moreover, MCS does not require advanced financial theory, and thus project managers who are not familiar with advanced finance theory are able to apply it.

# CONCLUDING REMARKS

## 6.1 - Concluding summary

In this research the RO model is used to study the construction of the NLA. The main objective is to investigate if incorporating flexibility into the NLA construction is worthwhile and, if so, what is its value. Thus, it is intended that the results obtained highlight the importance of flexibility which is quantifying by a phased investment option. In times of economic crisis and with the scarce of the public sector resources to invest in infrastructure projects this investigation presents an economically attractive alternative that allows dealing with future uncertainty.

After a brief introduction to the problem in question, the second chapter aims, first of all, at highlighting the profound changes that have occurred in the aviation industry in recent decades, mostly as a result of the market deregulation and the Schengen agreement. These profound changes have increased the number of uncertainties with which managers have to deal with during the strategic planning of an airport. The increase in the number of uncertainties is the reason why AMP became obsolete. The second part of the chapter focuses on explaining the traditional approach for ASP –AMP - highlighting its weaknesses and presenting recent and viable approaches, capable of dealing with future uncertainty.

The literature review emphasizes the need for an approach to validate and incorporate flexibility in projects of this nature, since traditional DCF are unable to. RO have their origin on the financial market, based on the seminal work of Merton and Scholes as well as on Merton's research [4] [5]. This approach is able to capture managerial flexibility reason why its framework was extended to several different fields in a short period after its emergence. At the end of third chapter the tools to value RO are presented, with particular attention to BOPM since this is the most appropriate model to model one uncertainty - the passenger demand - just as is the case of this research.

Prior to the emergence of this approach, all projects were seen taking into account a single decision – the go or no go decision. The incorporation of RO in projects increased the range of decisions, thus becoming possible to defer, stage investments, alter the operating scale, abandon, switch, grow and interact. The many similarities between RO and investment opportunities allowed to expand the scope for many different areas such as R & D, engineering and, the focus of this project, infrastructure. Concepts such as uncertainty and management flexibility are explained to understand how to make the most of the RO approach.

In the following years, the number of different fields for the application of RO increased since managers quickly realized that this methodology deals with uncertainty in a way never used before. The application of RO in infrastructure began at the very beginning of the 21st century. The main reason for resorting to this tool lies in the possibility of incorporating flexibility since the design phase of the project. As flexibility has the ability to manage uncertainty, this concept has gained much importance both academically and professionally.

Its importance in the field of infrastructure is raising the interest of several managers which aim to determine the real value of their project as well as take advantage of the many number of options as possible.

After highlighting the importance of the value of flexibility in a project, the common methods of design are presented. Once again the incorporation of flexibility in design project brings several benefits such as increasing the ability to manage opportunities and maximizing the expected value of a system over time.

The fourth chapter begins with an introduction to the company that until recently was managing airports in mainland Portugal and the Azores - ANA. Previous studies are described subsequently for the selection of the construction site for the NLA. The CTA presents itself as the best alternative. Portela Airport is then thoroughly analyzed to understand its limitations as well as the need of a new airport to accommodate LCCs' traffic. Finally the three scenarios, crucial to the research development, are presented and described.

The two most relevant scenarios developed in the research: one inflexible where the investment to construct the NLA was entirely made in the beginning of the project and a flexible one which had flexibility embedded in it, by making smaller investments up front, and expanding the airport when traffic was enough to justify it.

The model used to quantify the value of flexibility (through a phased investment option) is described in detail in Chapter 5. The growth rates, volatility and other relevant factors are explained, taking into account the variable to be modelled – passengers' demand. The use of this model allowed comparing the normal construction of the new airport (built initially to withstand its maximum capacity - 40 million passengers per year) with a modular construction (initially able to receive 10 million passengers per year).

The case study presented supports the hypothesis that it is possible to obtain a higher economic value of a project if the investments are phased according to the development of the traffic demand (variable modelled). The construction of the NLA is crucial, not only because the Portela airport is reaching its limit but also to allow for traffic differentiation, since this will be a LCA, reinforcing the position of Portela as an intercontinental hub for flag companies.

The results obtained confirm the hypothesis considered in this research. The value of the option to invest in a phased manner, for the period prescribed for study - 50 years - is 874.102 thousand euros. The option value is so significant that the project goes from unattractive (NPV for a 50 year period of - 236.197 thousand euros) to very attractive (NPV for a 50 year period of 637.905 thousand euros).

The sensitivity analysis performed to critical variables (growth rate and investments) highlighted the value of embedding flexibility in the construction of the NLA. Regardless of the critical variables values, the NPV in the flexible scenario broadly exceeded the one obtained in the inflexible scenario. Furthermore, the same change on the investment costs (25%) had a negative effect 4.64 times more pronounced in the scenario without flexibility when compared to the with flexible one. Meanwhile, MCS was used to validate the consistency of the model implemented, and consequently the results obtained. The results have not changed significantly thereby verifying the model's consistency.

The economic crisis affecting Europe and Portugal in particular requires looking for a flexible alternative to the construction and management of infrastructure projects. As previously mentioned, infrastructure projects finance has laid, traditionally, upon public domain. Nevertheless, the budget reduction in European countries can be seen as an opportunity for a new financing model for infrastructure projects, different from the traditional ones

In an environment of economic crisis it is highly advantageous to build in a modular way thereby taking greater advantage of a phased investment. The results obtained have confirmed what is assumed in this thesis - the flexibility is a tool that allows handling future uncertainty in order to capture the latent value in each project. By exceeding in over 800 million euros the NPV from the inflexible scenario, the value of flexibility demonstrates by itself the benefits of this tool when combined with RO.

Despite the simplicity of the results obtained through implementing the RO model, it becomes clear that waiting for more information before committing to an investment is a thought to consider, especially if this investment is coupled with a number of uncertainties and where high levels of capital expenditures are required.

## **6.2 - Future work**

For future development some improvements or relevant aspects to consider are indicated, arising from simplifications and aggregations performed as well as data and assumptions made throughout this research:

Firstly, the loss of traffic in Portela airport was not considered for the base case scenario. It would be interesting to estimate the percentage of lost traffic per year, where it would be redirected to, how companies would reallocate their fleets and its impact on TAP – the major Portuguese airline.

Secondly, only one variable was modeled – the passengers demand. Several other were left behind (e.g. passengers' terminal limit and number of hours Portela's airport can work in full capacity). It would be academically interesting to analyze these variables that can bind to anticipate the construction of the new airport since the number of passengers per year is not the only limitation of an airport.

Thirdly, the lack of financial information from ANA airports forced to assume some values that may not be the most suitable ones. Furthermore, the lack of information of traffic differentiation (FSC and LCC) per airport is scarce. If more data was available the final result might have been more accurate

Finally, applying this model to other airports would be interesting to see whether, regardless of the country in which the airport is built, it is worthwhile to incorporate flexibility in planning and design of an airport infrastructure.

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## Annex 1 - Financial stock option example

Based on the existing literature in the area of real options, this simple example (and unrealistic) attempts to explain the basics of FO theory and relate it to the real options approach. An option in the financial market is similar to a real option. A simple example with a call option is explained next (the transaction cost is eliminated for the purpose of this example).

Assume that a stock (S) has a value of 60€ on July 1<sup>st</sup>, 2012. Since an investor expects the stock to rise substantially he/she is interested in investing (purchasing the stock). Being so, this investor pays the option premium (P) of 1€ (acquiring the option). The exercise price is 64€ and the maturity date is August 1<sup>st</sup>, 2012. The probability of the stock rising above 65€ is 65%. The following figure represents this situation.

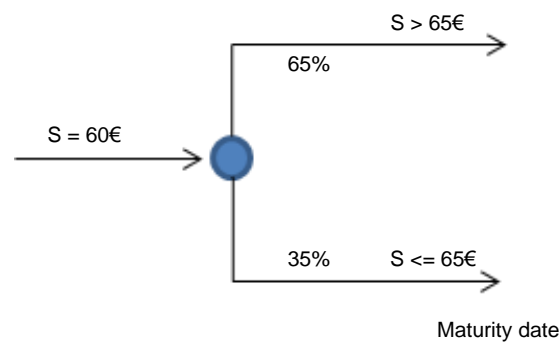


Figure A1 - Call option on a stock

If S obtains a value exceeding € 65, the investor will exercise the option and profit from the option obtained. His earnings can be calculated by  $S - P$  if he exercises the option. On the other hand, if the value remains below the 54 €, the investor does not take the initiative to exercise the option, as this has no value. The profit or loss of the investor who acquires the action can be written as follows:  $\text{MAX}(-1, SP)$ . Figure B2 represents the structure of the option payoff.

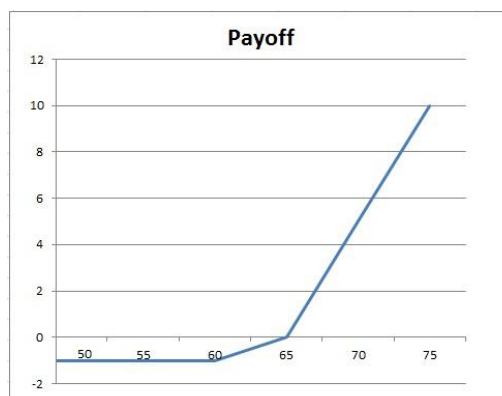


Figure A2 - Call option payoff structure

The company should not invest when the option is 'on the money' – when  $S \leq X$  (expenditure requires to acquire the project). On the other hand, if the value is 'in the money', the company should invest. Real options allow an increased managerial flexibility.



## Annex 2- Literature review on real options

Table B1 – Summary of literature overview on real options

	2003			2004			
<i>Authors</i>	Smit	Zhao and Tseng	Ford; Lander and Voyer	Bowe and Leeb	Garvin and Cheah	Cui et al,	Law, Mackay and Nolan
<i>Fields of application</i>	Airport	Parking Garage	Large Engineering Projects	High-Speed Rail	Toll Road	Highway	Rail-line
<i>Reference</i>	[115]	[221]	[151]	[222]	[223]	[224]	[225]

	2004	2005	2006		2007		
<i>Authors</i>	Zhao; Sundararajan and Tseng	Wang and de Neufville	Cheah and Liu	Pereira; Rodrigues and Armada	De Neufville	Alonso-Conde; Brown and Rojo-Suarez	CEGEA AND TRENMO
<i>Fields of application</i>	Highway	Hydropower Station	Bridge	Airport	Large-scale Projects	Toll Road	Airport
<i>Reference</i>	[226]	[122]	[227]	[228]	[80]	[229]	[10]

	2007						
<i>Authors</i>	Ohama	Rivey	Chiara; Garvin and Vecer	Gil	Pimentel; Azevedo-Pereira and do Couto	Chambers	De Neufville
<i>Fields of application</i>	Airport	Airport	Toll Road	Airport	Rail Transport	Airport	Airport
<i>Reference</i>	[118]	[230]	[117]	[116]	[231]	[46]	[84]

	2007			2008			
<i>Authors</i>	De Neufville; Lee and Scholtes	Zhao and Tseng	Masek	Ohama	Kwakkel <i>et al.</i>	Maseda	Brandão and Saraiva
<i>Fields of application</i>	Hospital	Facility	Airport	Tokyo Bay aqua-line	Airport	Hospital	Toll Road
<i>Reference</i>	[232]	[233]	[234]	[235]	[110]	[219]	[236]

	2008	2009				
<i>Authors</i>	De Neufville	Blank; Baidya and Dias	Huber	Michailidis et al.	Park and Lim	Zhang and Babovic
<i>Fields of application</i>	Airport	Toll Road	Airport	Irrigation Dam	Power Plants	Water Supply System
<i>Reference</i>	[90]	[237]	[111]	[238]	[239]	[240]

2010					2011		
<i>Authors</i>	Sitruk	Kwakkel; Walker and Marchau	Athias and Saussier	Shan; Garvin and Kumar	Corato and Moretto	Vajdić and Damnjanović	Padhy and Sahu
<i>Fields of application</i>	Railway	Airport	Infrastructure Concession	Toll Highway Concession	Biogas Plant	Highway	Petroche- mical Industry
<i>Reference</i>	[241]	[7]	[242]	[243]	[244]	[245]	[246]
2012					2013		
<i>Authors</i>	Zhang and Babovic	Cruz and Marques	Alexander and Chen	Clapp <i>et al.</i>	Pinon; Garcia and Mavris	Zambujal- Oliveira	Jain; Roelofs and Oosterlee
<i>Fields of application</i>	Maritime domain protection	Hospital	Real Estate	Residential Development	Airport	Natural gas- fired plants	Nuclear Power Plants
<i>Reference</i>	[247]	[2]	[248]	[249]	[120]	[250]	[251]

### Annex 3 - Monte Carlo simulation distributions

Mean value = 6,22%

Standard deviation = 0,622%

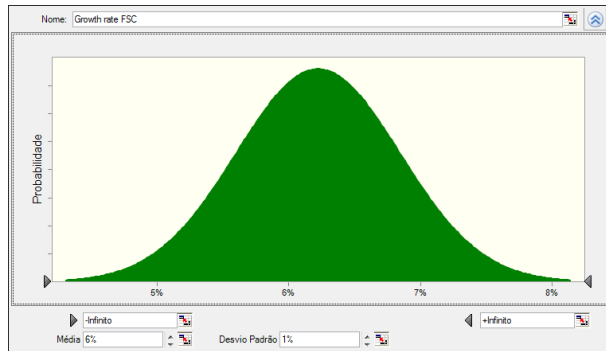


Figure C1 - Low-Cost carriers' growth rate normal distribution

Mean value = 17,87%

Standard deviation = 1,787%

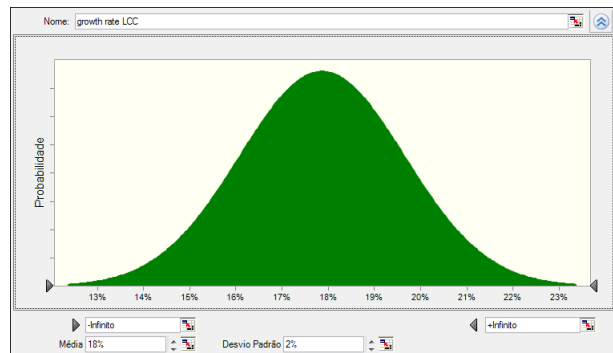


Figure C2 – Full Service carriers' growth rate normal distribution

Mean value = 4,11%

Standard deviation = 0,411%

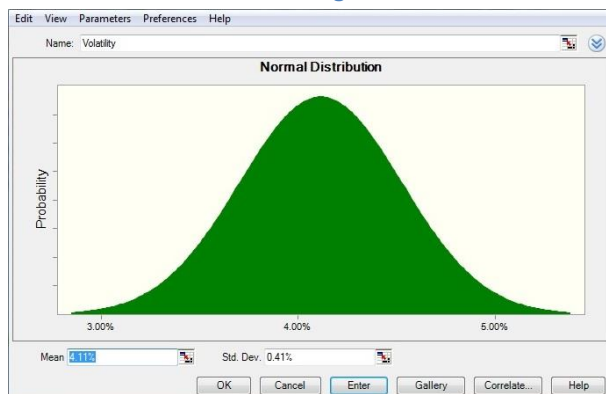


Figure C3 – Full Service carriers' volatility normal distribution

Mean value = 9,3%

Standard deviation = 0,93%

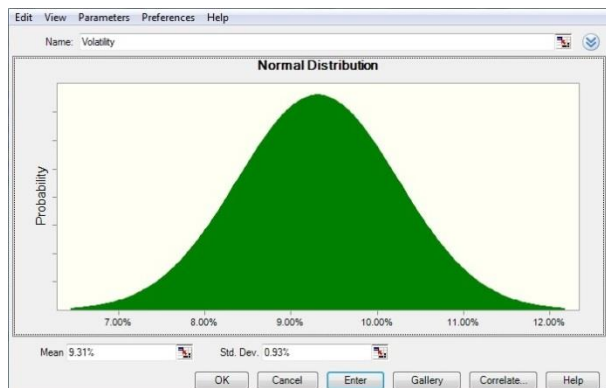


Figure C4 – Full Service carriers' volatility normal distribution

Mean value = 177.389 thousand €

Minimum value = 155.215,375 thousand €

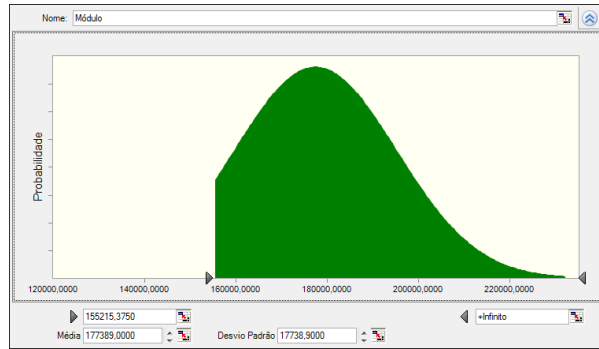


Figure C5 - 5 million passengers' module loan value

Mean value = 177.389 thousand €

Minimum value = 136.303,375 thousand €

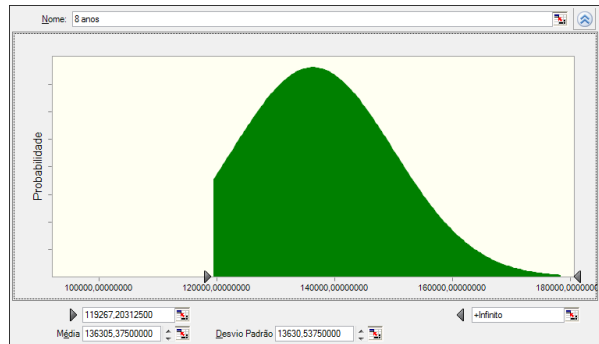


Figure C6 - 10 million passengers' module + runway loan value

Mean value = 183.916,25 thousand €

Minimum value = 160926,72 thousand €

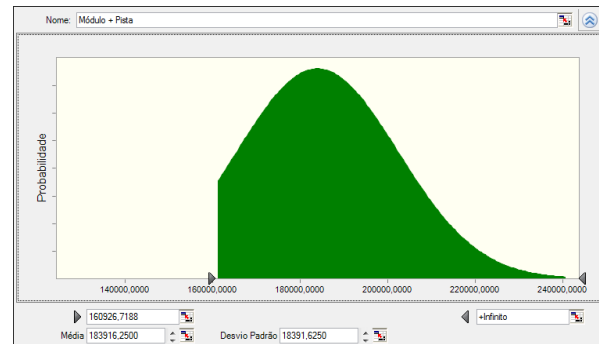


Figure C7 - 5 million passengers' module + 2nd runway loan value