

FLEXIBILITY IN THE DEVELOPMENT OF AIRPORTS

A Real Options Valuation

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To my Parents

Prediction is very difficult, especially about the future

Niels Bohr

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ABSTRACT

Investing in large transport infrastructures, as is the case of airports, is a risky venture subjected to all kind of uncertainties. Traffic volatility is one of the major concerns to airport authorities, public policy makers, regulators, and other stakeholders.

Traditional airport planning paradigms, based on master plans and forecasts, seem inadequate to deal with a highly volatile environment in terms of economic, technological, and technical conditions.

To try to overcome those sources of uncertainty concepts like flexible design of projects has arisen. To be successful in highly competitive and uncertain markets, airports have to be (dynamically) adaptable to changeable engineering systems, and create reliable links to the air transport value chain.

This research focus on the analysis of the economic value of flexible airport design under a *real options* approach, which provides a framework to fill in the limitations of traditional valuation models, like the standard net present value.

The analysis was conducted using a model developed by the author, which was empirically implemented in a sample of Portuguese airports, to estimate the value underlying the flexibility in the design of different airport subsystems.

The model can be regarded as a support system, able to help decision makers and project managers in strategic and tactical decisions regarding airport infrastructure project design, execution and management.

KEYWORDS: Real Options, Uncertainty, Flexibility, Airport Design, Project Evaluation.

RESUMO

O investimento em infra-estruturas de transportes de dimensão elevada, como é o caso dos aeroportos, constitui um negócio arriscado sujeito aos mais variados tipos de incerteza. A volatilidade do tráfego é das preocupações primordiais para as autoridades aeroportuárias, entidades públicas, reguladores e outros *stakeholders*.

As técnicas tradicionalmente utilizadas no planeamento de aeroportos, baseadas em *master plans* e previsões de tráfego, têm-se revelado inadequadas para lidar com um mercado muito volátil em termos económicos, tecnológicos e de condições técnicas.

Conceitos tais como o design flexível de projectos aeroportuários têm aparecido como meio para enfrentar essas fontes de incerteza. Para ter sucesso neste mercado altamente competitivo e incerto, os aeroportos têm que ser transformados em sistemas de engenharia mutáveis, tornando-se uma componente fiável da cadeia de valor do sector da aviação.

Utilizando uma abordagem baseada nas *opções reais*, esta pesquisa visa determinar o valor económico subjacente à concepção de um aeroporto de uma maneira flexível. Esta abordagem pretende ultrapassar algumas limitações que os modelos tradicionais de avaliação de projectos, como o conhecido valor actual líquido, possuem.

Esta análise foi conduzida recorrendo a um modelo desenvolvido pelo autor, empiricamente implementado numa amostra de aeroportos localizados em Portugal, visando a estimação do valor que tal flexibilidade nos diferentes subsistemas de um aeroporto poderia acarretar para o valor final do projecto.

Este modelo pode ser encarado como um sistema de apoio à decisão, capaz de ajudar decisores e gestores de projecto a tomar decisões estratégicas e táticas relativamente ao desenvolvimento, execução e gestão de projectos de infra-estruturas aeroportuárias.

PALAVRAS-CHAVE: Opções Reais, Incerteza, Flexibilidade, Concepção de Aeroportos, Avaliação de Projectos.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	i
ABSTRACT	iii
RESUMO	v
 1. INTRODUCTION	 1
1.1. THE PROBLEM	1
1.2. A NEW PARADIGM	1
1.3. VALUATION METHODOLOGY	1
1.4. THESIS OBJECTIVES	1
1.5. THESIS STRUCTURE	2
 2. UNCERTAINTY IN AIRPORT DEVELOPMENT	 3
2.1. EVOLUTION OF THE INDUSTRY	3
2.1.1. FROM WWII TO THE 21 ST CENTURY	3
2.1.1.1. Deregulation Process	3
2.1.1.2. Airlines and Airports	4
2.1.1.3. The Appearance of the Low-Cost Carriers	6
2.1.2. TRADITIONAL AIRPORT PLANNING	9
2.2. THE VALUE OF FLEXIBILITY	9
2.2.1. FORECASTS ARE ALWAYS WRONG	9
2.2.2. FLEXIBLE DESIGN – TAKING ADVANTAGE OF UNCERTAINTY	10
 3. STANDARD VALUATION MODELS	 13
3.1. DISCOUNTED CASH FLOW	13
3.1.1. NET PRESENT VALUE	13
3.1.1.1. Mathematical Formulation	13
3.1.1.2. The Decision-Making Process	14
3.1.1.3. Relevant Cash Flows	14
3.1.2. WEIGHTED AVERAGE COST OF CAPITAL	15
3.1.3. COST OF DEBT AND COST OF EQUITY	15
3.2. FREE CASH FLOW VS. CAPITAL CASH FLOW	17

3.3. THE DISCOUNTED CASH FLOW MODELS SHORTCOMINGS 18

4. OPTIONS 21

4.1. FINANCIAL OPTIONS 21

4.1.1. VALUATION MODELS 21

4.1.1.1. Black-Scholes Model 21

4.1.1.2. Binomial Lattices 23

4.1.1.3. Simulations 24

4.2. REAL OPTIONS 26

4.2.1. TYPES OF REAL OPTIONS 28

4.2.1.1. Real options *on* projects 28

4.2.1.2. Real options *in* projects 29

4.2.2. VALUING REAL OPTIONS 30

4.2.3. SOME USES OF REAL OPTIONS 32

4.2.3.1. Options to defer/expand 32

4.2.3.2. Options to abandon 33

4.2.3.3. Examples 33

4.2.4. CRITICISM OF REAL OPTIONS 34

5. THE MODEL 35

5.1. MODEL EXPLANATION 35

5.1.1. TYPES OF AIRPORTS CONSIDERED 35

5.1.2. VALUATION PROCEDURE 36

5.1.2.1. Inflexible Scenarios 36

5.1.2.2. Flexible Scenarios 37

5.1.2.3. Sensitivity Analysis and Monte Carlo Simulations 38

5.2. FLEXIBLE SUBSYSTEMS CONSIDERED 39

5.3. TRAFFIC FORECAST 40

5.4. INFLOWS AND OUTFLOWS 40

5.5. MODEL SPECIFICATION AND PARAMETERIZATION 41

5.6. BINOMIAL LATTICES INPUTS 42

6. RESULTS	43
6.1. FINANCIAL PARAMETERS	43
6.2. INFLEXIBLE SCENARIO	43
6.3. FLEXIBLE SCENARIO	45
6.3.1. OPTION VALUE	48
6.3.2. ABANDONMENT OPTION	49
6.4. LOW-COST AIRPORT WITH LOWER ANNUAL GROWTH RATE	50
6.5. COMPARISON OF VALUATION MODELS	52
6.6. SENSITIVITY ANALYSIS	53
6.6.1. DETERMINATION OF CORRELATIONS BETWEEN VARIABLES	56
6.7. MONTE CARLO SIMULATIONS	57
6.7.1. ASSUMPTIONS	57
6.7.2. FULL SERVICE AIRPORT RESULTS	58
6.7.3. LOW-COST AIRPORT RESULTS	58
6.7.3.1. Simulation without Financial Variables	58
6.7.3.2. Simulation with Financial Variables	59
6.7.4. COMPARISON BETWEEN SIMULATIONS WITH AND WITHOUT CORRELATING VARIABLES	61
6.7.4.1. Full Service Airport	61
6.7.4.2. Low-Cost Airport	62
6.8. SUMMARY	62
7. CONCLUSIONS	65
REFERENCES	67
APPENDICES	A.1
A.1. PURPOSE OF AN AIRPORT MASTER PLAN	A.1
A.1.1. GENERAL PART	A.1
A.1.2. TYPES OF ACTIONS DURING THE AIRPORT MASTER PLANNING	A.1
A.1.3. STEPS IN THE PLANNING PROCESS	A.2
A.1.4. PLAN UPDATE RECOMMENDATIONS	A.2
A.2. EXAMPLES OF DIFFERENCES BETWEEN TRAFFIC FORECASTS AND ACTUAL TRAFFIC	A.3
A.3. ASSUMPTIONS OF THE CAPITAL ASSET PRICING MODEL	A.4

A.4. ASSUMPTIONS OF THE BLACK-SCHOLES MODEL	A.5
A.5. FULL INVESTMENT COSTS ON THE TWO TYPES OF AIRPORTS CONSIDERED.....	A.6
A.6. RESULTS FOR THE INFLEXIBLE SCENARIO	A.8
A.6.1. FULL SERVICE AIRPORT	A.8
A.6.2. LOW-COST AIRPORT	A.9
A.7. RESULTS FOR THE FLEXIBLE SCENARIO	A.10
A.7.1. FULL SERVICE AIRPORT	A.10
A.7.2. LOW-COST AIRPORT	A.21
A.8. SENSITIVITY ANALYSIS COMPLETE RESULTS.....	A.32
A.9. MONTE CARLO SIMULATIONS COMPLETE RESULTS	A.41
A.9.1. ASSUMPTIONS	A.41
A.9.1.1. Full Service Airport.....	A.41
A.9.1.2. Low-Cost Airport	A.43
A.9.2. RESULTS.....	A.46
A.9.2.1. Full Service Airport.....	A.46
A.9.2.2. Low-Cost Airport without Financial Variables.....	A.52
A.9.2.3. Low-Cost Airport with Financial Variables.....	A.58

LIST OF FIGURES

Fig. 2.1. – Yield from 1937 to 2007, adjusted to 1978 prices.....	4
Fig. 2.2. – Point-to-point and hub-and-spoke operations.....	5
Fig. 2.3. – Services offered by an airport	6
Fig. 2.4. – Sources of uncertainty and their context	11
Fig. 2.5. – Example of the hockey-stick value of flexibility	12
Fig. 3.1. – Security market line	16
Fig. 4.1. – Initial stages of a binomial lattice.....	24
Fig. 4.2. – Monte Carlo simulation process	25
Fig. 4.3. – Four-step valuation process for real options.....	32
Fig. 4.4. – The option to delay or expand a project	32
Fig. 4.5. – The option to abandon a project.....	33
Fig. 5.1. – Final results produced by the model.....	38
Fig. 6.1. – Probabilities for passenger activity in year 51 for a full service airport.....	46
Fig. 6.2. – Probabilities for passenger activity in year 51 for a low-cost airport	46
Fig. 6.3. – Example of a triangular distribution	57
Fig. A.1. – Monte Carlo simulation results for a full service airport, inflexible scenario, FCF model. A.	46
Fig. A.2. – Monte Carlo simulation results for a full service airport, inflexible scenario, CCF model A.	47
Fig. A.3. – Monte Carlo simulation results for a full service airport, flexible scenario, FCF model.... A.	48
Fig. A.4. – Monte Carlo simulation results for a full service airport, flexible scenario, CCF model ... A.	49
Fig. A.5. – Monte Carlo simulation results for a full service airport, option value, FCF model..... A.	50
Fig. A.6. – Monte Carlo simulation results for a full service airport, option value, CCF model	51
Fig. A.7. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, FCF model..... A.	52
Fig. A.8. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, CCF model A.	53
Fig. A.9. – Monte Carlo simulation results for a low-cost airport, flexible scenario, FCF model	54
Fig. A.10. – Monte Carlo simulation results for a low-cost airport, flexible scenario, CCF model..... A.	55
Fig. A.11. – Monte Carlo simulation results for a low-cost airport, option value, FCF model	56
Fig. A.12. – Monte Carlo simulation results for a low-cost airport, option value, CCF model	57
Fig. A.13. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, FCF model, including financial variables.....	A.58
Fig. A.14. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, CCF model, including financial variables.....	A.59

Fig. A.15. – Monte Carlo simulation results for a low-cost airport, flexible scenario, FCF model, including financial variables.....	A.60
Fig. A.16. – Monte Carlo simulation results for a low-cost airport, flexible scenario, CCF model, including financial variables.....	A.61
Fig. A.17. – Monte Carlo simulation results for a low-cost airport, option value, FCF model, including financial variables	A.62
Fig. A.18. – Monte Carlo simulation results for a low-cost airport, option value, CCF model, including financial variables	A.63
Fig. A.19. – Monte Carlo simulation results for a low-cost airport, equity beta	A.64
Fig. A.20. – Monte Carlo simulation results for a low-cost airport, cost of debt	A.65
Fig. A.21. – Monte Carlo simulation results for a low-cost airport, cost of equity.....	A.66
Fig. A.22. – Monte Carlo simulation results for a low-cost airport, expected asset return.....	A.67
Fig. A.23. – Monte Carlo simulation results for a low-cost airport, WACC.....	A.68

LIST OF TABLES

Table 2.1. – Freedom of action of airlines before and after deregulation	3
Table 2.2. – Differences between LCCs and legacy carriers requirements in an airport.....	8
Table 2.3. – Risks, uncertainties and data sources for a project.....	10
Table 2.4. – Old and new paradigm for project development.....	12
Table 3.1. – Disadvantages of DCF method: assumptions vs. reality	19
Table 4.1. – Variables affecting call and put prices	22
Table 4.2. – Different types of real options.....	28
Table 4.3. – Comparison between an American call option and a real option on a project.....	29
Table 4.4. – Comparison between real option <i>in</i> and <i>on</i> projects	30
Table 4.5. – Advantages and drawbacks of each method when evaluating real options	31
Table 5.1. – Investments on the two of airports considered.....	39
Table 5.2. – Passenger related cash flows	41
Table 5.3. – Data inputs for the binomial lattices.....	42
Table 6.1. – Estimation of financial variables	43
Table 6.2. – Results for the inflexible scenario.....	44
Table 6.3. – Results for the inflexible scenario, with new data.....	45
Table 6.4. – Results for the flexible scenario.....	47
Table 6.5. – Results for the flexible scenario, with new data	47
Table 6.6. – Option value	48
Table 6.7. – Option value, with new data	48
Table 6.8. – Results for the abandonment option.....	49
Table 6.9. – Option value for the abandonment option.....	49
Table 6.10. – Abandonment option value.....	50
Table 6.11. – Results for inflexible low-cost airports, with different annual growth rates	51
Table 6.12. – Results for flexible low-cost airports, with different annual growth rates	51
Table 6.13. – Option value for low-cost airports, with different annual growth rates.....	51
Table 6.14. – Differences between the two models of valuation used for both types of airports	52
Table 6.15. – Differences between the two models of valuation used for low-costs airports, with different sources of traffic related data.....	53
Table 6.16. – Sensitivity analysis for the inflexible scenarios.....	54
Table 6.17. – Sensitivity analysis for the flexible scenarios	55
Table 6.18. – Monte Carlo simulation results for a full service airport	58

Table 6.19. – Monte Carlo simulation results for a low-cost airport.....	59
Table 6.20. – Monte Carlo simulation results for a low-cost airport, including financial variables	60
Table 6.21. – Comparison between Monte Carlo simulation results with and without correlations, for a full service airport.....	61
Table 6.22. – Comparison between Monte Carlo simulation results with and without correlations, for a low-cost airport	62
Table A.1. – Traffic forecast for Lisbon Airport (Portela) by different entities	A.3
Table A.2. – Difference between traffic forecast (one and ten years earlier) for American domestic flights and actual enplanements	A.4
Table A.3. – Full investments on a full service airport	A.6
Table A.4. – Full investments on a low-cost airport.....	A.7
Table A.5. – Results for the inflexible scenario for a full service airport.....	A.8
Table A.6. – Results for the inflexible scenario for a low-cost airport.....	A.9
Table A.7. – Binomial lattice for expected passenger movements for a full service airport.....	A.10
Table A.8. – Binomial lattice for the probabilities associated with each node for a full service airport.....	A.11
Table A.9. – Binomial lattice for the need for expansion for a full service airport	A.12
Table A.10. – Binomial lattice for the total investment needed for a full service airport	A.13
Table A.11. – Binomial lattice for the partial investment needed for a full service airport	A.14
Table A.12. – Binomial lattice for the anticipation of the partial investment by 3 years for a full service airport.....	A.15
Table A.13. – Binomial lattice for the expected cash flows for a full service airport.....	A.16
Table A.14. – Binomial lattice for probability weighted expected cash flows for a full service airport.....	A.17
Table A.15. – Flexible scenario free cash flows results for a full service airport.....	A.18
Table A.16. – Flexible scenario capital cash flows results for a full service airport.....	A.18
Table A.17. – Binomial lattice for the abandonment option for a full service airport	A.19
Table A.18. – Flexible scenario free cash flows results for the abandonment option for a full service airport.....	A.20
Table A.19. – Flexible scenario capital cash flows results for the abandonment option for a full service airport.....	A.20
Table A.20. – Binomial lattice for expected passenger movements for a low-cost airport	A.21
Table A.21. – Binomial lattice for the probabilities associated with each node for a low-cost airport	A.22
Table A.22. – Binomial lattice for the need for expansion for a low-cost airport	A.23
Table A.23. – Binomial lattice for the total investment needed for a low-cost airport.....	A.24
Table A.24. – Binomial lattice for the partial investment needed for a low-cost airport.....	A.25

Table A.25. – Binomial lattice for the anticipation of the partial investment by 3 years for a low-cost airport	A.26
Table A.26. – Binomial lattice for the expected cash flows for a low-cost airport.....	A.27
Table A.27. – Binomial lattice for probability weighted expected cash flows for a low-cost airport...	A.28
Table A.28. – Flexible scenario free cash flows results for a low-cost airport.....	A.29
Table A.29. – Flexible scenario capital cash flows results for a low-cost airport.....	A.29
Table A.30. – Binomial lattice for the abandonment option for a low-cost airport	A.30
Table A.31. – Flexible scenario free cash flows results for the abandonment option for low-cost airportA.31	
Table A.32. – Flexible scenario capital cash flows results for the abandonment option for a low-cost airport	A.31
Table A.33. – Sensitivity analysis variables and respective variations	A.32
Table A.34. – Sensitivity analysis for a full service airport, inflexible scenario, FCF model.....	A.33
Table A.35. – Sensitivity analysis for a full service airport, inflexible scenario, CCF model.	A.34
Table A.36. – Sensitivity analysis for a low-cost airport, inflexible scenario, FCF model.	A.35
Table A.37. – Sensitivity analysis for a low-cost airport, inflexible scenario, CCF model.....	A.36
Table A.38. – Sensitivity analysis for a full service airport, flexible scenario, FCF model.	A.37
Table A.39. – Sensitivity analysis for a full service airport, flexible scenario, CCF model.....	A.38
Table A.40. – Sensitivity analysis for a low-cost airport, flexible scenario, FCF model.	A.39
Table A.41. – Sensitivity analysis for a low-cost airport, flexible scenario, CCF model.....	A.40
Table. A.42. – Monte Carlo simulation results for a full service airport, inflexible scenario, FCF modelA.46	
Table. A.43. – Monte Carlo simulation results for a full service airport, inflexible scenario, CCF modelA.47	
Table. A.44. – Monte Carlo simulation results for a full service airport, flexible scenario, FCF modelA.48	
Table. A.45. – Monte Carlo simulation results for a full service airport, flexible scenario, CCF modelA.49	
Table. A.46. – Monte Carlo simulation results for a full service airport, option value, FCF model....	A.50
Table. A.47. – Monte Carlo simulation results for a full service airport, option value, CCF model....	A.51
Table. A.48. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, CCF modelA.52	
Table. A.49. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, CCF modelA.53	
Table. A.50. – Monte Carlo simulation results for a low-cost airport, flexible scenario, FCF model .	A.54
Table. A.51. – Monte Carlo simulation results for a low-cost airport, flexible scenario, CCF model .	A.55
Table. A.52. – Monte Carlo simulation results for a low-cost airport, option value, FCF model.....	A.56
Table. A.53. – Monte Carlo simulation results for a low-cost airport, option value, CCF model	A.57
Table. A.54. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, FCF model, including financial variables	A.58
Table. A.55. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, CCF model, including financial variables.....	A.59

Table. A.56. – Monte Carlo simulation results for a low-cost airport, flexible scenario, FCF model, including financial variables.....	A.60
Table. A.57. – Monte Carlo simulation results for a low-cost airport, flexible scenario, CCF model, including financial variables.....	A.61
Table. A.58. – Monte Carlo simulation results for a low-cost airport, option value, FCF model, including financial variables	A.62
Table. A.59. – Monte Carlo simulation results for a low-cost airport, option value, CCF model, including financial variables	A.63
Table. A.60. – Monte Carlo simulation results for a low-cost airport, equity beta	A.64
Table. A.61. – Monte Carlo simulation results for a low-cost airport, cost of debt	A.65
Table. A.62. – Monte Carlo simulation results for a low-cost airport, cost of equity.....	A.66
Table. A.63. – Monte Carlo simulation results for a low-cost airport, expected asset return.....	A.67
Table. A.64. – Monte Carlo simulation results for a low-cost airport, WACC.....	A.68

LIST OF SYMBOLS

\$ - US dollar

$(r_M - r_F)$ – market risk premium

€ - euro

C_0 – cash flow at instant zero

C_i – cash flow at instant i

d – decrease factor

g – level of financial leverage of a project

K – strike price of option

K_A – expected asset return

K_D – cost of debt

K_E – cost of equity

n – life of the project

$N(d)$ – cumulative normal probability function

p – probability increase factor

r – discount rate (Chapter 3)

r – riskless interest rate corresponding to life of option (Chapter 4)

r_E – rate of return of the company

r_F – risk-free rate

r_M – level of market return

S – current value of the underlying asset

t – corporate tax (Chapter 3)

t – time to expiration of option (Chapter 4)

u – increase factor

y – dividends paid on the underlying asset

β_A – asset beta

β_D – debt beta

β_E – equity beta

Δt – length of each time period

v – average grow rate

σ – standard deviation

σ^2 – variance in value of the underlying asset

LIST OF ACRONYMS

ANA – ANA Aeroportos de Portugal, S.A.

AOV – Abandonment Option Value

BS – Black–Scholes

CAPEX – Capital Expenditures

CAPM – Capital Asset Pricing Model

CCF – Capital Cash Flow

CEGEA – Centro de Estudos de Gestão e Economia Aplicada – Faculdade de Economia e Gestão da Universidade Católica Portuguesa

DCF – Discounted Cash Flow

EU – European Union

FAA – Federal Aviation Administration

FCF – Free Cash Flow

FSA – Full Service Airport

GPD – Gross Domestic Product

GPS – Geographic Positioning System

IATA – International Air Transport Association

ICAO – International Civil Aviation Organization

LCA – Low–Cost Airport

LCC – Low–Cost Carrier

MIT – Massachusetts Institute of Technology

MPax – Million Passengers (per year)

NPV – Net Present Value

OV – Option Value

RO – Real Options

ROT – Real Options Theory

SARS – Severe Acute Respiratory Syndrome

SML – Security Market Line

USA – United States of America

WACC – Weighted Average Cost of Capital

WWII – World War II

1

INTRODUCTION

1.1. THE PROBLEM

For decades, traditional airport planning was, most of the times, based on predetermined master plans and forecasts for aviation activity, which has been accepted as the paradigm for implementing a strategy, both economical and physical, to develop an airport (Caves and Gosling, 1999).

Recent changes in the aviation sector, like the liberalization of the air space and the emergence of Low-Cost Carriers (LCC), as well as major international events, like the 9/11 attacks in the United States of America in 2001, the international financial crisis of the late 2008, the health crisis of the Severe Acute Respiratory Syndrome (SARS) in 2002/2003, the avian flu (H5N1) since 2005 and the *influenza A* (H1N1) outbreak in 2009, have questioned this model about its inflexible assumptions, suggesting that a new framework for airport design, development and management should be needed.

1.2. A NEW PARADIGM

Rather than changing the design of an airport altogether (most airport's subsystems – both on the air side or the land side –, regardless all technological improvements, remain in essence the same), the new trend should focus on the flexible development of those subsystems (Neufville, 2008).

In an uncertain world, such as the one in which airports operate, flexibility is a major addition to increase the chances of having a successful project: by being proactive, management can take advantage of unexpected upside opportunities, while reducing exposure to downside risks (Cardin, Neufville, 2008).

1.3. VALUATION METHODOLOGY

This research aims at appraising different airport subsystems, such as taxiways, and terminal buildings, that, arguably, may be more appropriately developed under a modular concept and gauge that flexibility using different valuation models.

These models include the standard net present value (NPV), which assumes the project will meet its deterministic expected cash flows with no managerial intervention, with all the uncertainty being reflected in the risk-adjusted discount rate.

As is widely recognized, this model has some limitations, like the aforementioned managerial inflexibility, which treats every project like a go-or-no-go decision, and is unable to reflect new information on project implementation and execution. This procedure may be acceptable in a simple everyday

small scale project, but in more complex systems, like an airport, is likely to bias the project's economic value creation / destruction by overlooking the effects of managerial decision-making in the project execution and management, which choices configure a right, not an obligation, to follow a certain course of action in the future.

The seminal work of Black and Scholes (1973) and Merton (1973), provide the theoretical foundations for valuing contingent financial assets, such as options, which economic worth is conditional on the value of an underlying asset in future (uncertain) states of the world. This valuation model subsequently was applied to the valuation of optionalities on real assets: the so called real options (Myers, 1977).

The thesis shows an application of real options to value the flexibility in designing and managing an airport project in its passenger service.

1.4. THESIS OBJECTIVES

One of the main objectives of this research is to assess the value underlying the flexibility in the design of the different subsystems of an airport. A model, developed by the author, was used in order to achieve that goal.

The development of this model – which can constitute a support system to help decision makers and project managers in strategic and tactical decisions regarding airport infrastructure project design, execution and management – was the other main objective of this study.

In this model, which considers the different airport subsystems as a whole, a number of different scenarios, regarding two different types of airports, were studied and valued (not only by real options, but also by the more traditional model of net present value) in order to estimate how considering flexibility in the development of airports increases its value. Data inputs for the model were largely based on a sample of Portuguese airports, which is now facing new challenges with the construction of a new international airport in Lisbon that might reshape the entire sector in the country.

1.5. THESIS STRUCTURE

The thesis is organized as follows:

- Chapter 2, *Uncertainty in Airport Development*, initiates the topic of uncertainty in the aviation industry, its past and current states. This subject is then enlarged to discuss how flexibility can add value to large investments, like airports and other engineering systems.
- Chapter 3, *Standard Valuation Models*, provides an overview of the main tools traditionally used when analyzing the feasibility of a project. In the later sections of the chapter, it is discussed how this standard models might fail when evaluating projects that do not remain immutable during its life period.
- Chapter 4, *Options*, introduces the topic of options, its history in the financial world and its later applications to real assets – *real options*. Valuation models and uses of real options are also presented in this chapter.
- Chapter 5, *The Model*, explains the model developed by the author, its assumptions and constraints.
- Chapter 6, *Results*, presents the results obtained by the model and its implications in the subject being studied.
- Chapter 7, *Conclusions*, synthesizes the work done and the main conclusions regarding the preceding chapters. It also presents ideas to expand the research done during this thesis.

2

UNCERTAINTY IN AIRPORT DEVELOPMENT

2.1. EVOLUTION OF THE INDUSTRY

2.1.1. FROM WWII TO THE 21ST CENTURY

2.1.1.1. Deregulation Process

The modern aviation sector started to take shape in the 1950's after the end of World War II. From that time onwards, the players in the business – airlines and airports owners –, operated in an highly regulated, stable, and predictable environment, which allowed them to make long-term forecasts and to have “faith” that the conditions in the following years would remain essentially unchanged.

Since 1978, with the United States' Airline Deregulation Act, which removed government control over fares, routes, and market entry for new airlines, the scenery started to change. Nowadays new players operate in the business and market conditions have changed for everyone.

Companies started losing markets they *have* taken for granted and kept for decades, while new opportunities arose in routes that previously were overly protected by regulations (Table 2.1.). Airports, free of the bureaucratic process that hindered competition between them, started to compete for the airlines attention, making airports, like Atlanta, become huge international hubs with more than 90 million passengers annually, and others, like Kansas City, lose almost all their customers when companies – TWA in the case of Kansas City – decide to move to another airport or simply went bankrupt (Neufville, 2008).

Table 2.1 – Freedom of action of airlines before and after deregulation.

Source: Neufville (2008)

Choice	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 type	Often controlled	Freedom to choose	Capacity wars

In Europe the deregulation process started in 1987, and although more gradual¹ than its American counterpart, in essence it was very similar. By 1997, the regulatory framework became almost identical to the United States (USA) domestic market (Button *et al.*, 2005). In 2008, even the air space between the USA and all 27 countries of the European Union (EU)² became deregulated without restrictions on routes, the number of flights, or prices charged.

This deregulation trend yielded an economic surplus for consumers which is reflected in Figure 2.1., which shows an average annual geometric growth rate of -2,63 percent over a period of 71 years on (real) price of flying a mile in the US. This reduction in fares made the air travel a more democratic mean of transportation, allowing a worldwide growth rate in passenger traffic of more than 8 percent a year in the last half of the 20th century (Neufville, 2000).

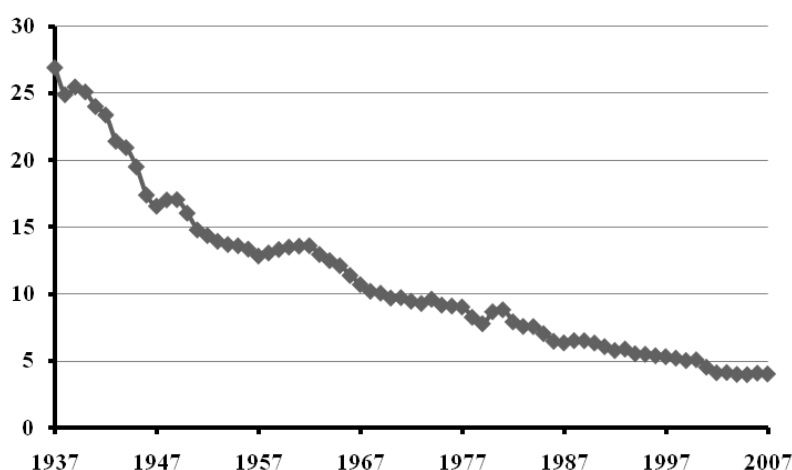


Fig. 2.1. – Yield – price (in \$US cents) a passenger pays to fly a mile – from 1937 to 2007 including all flights in the USA, adjusted to 1978 prices (the year of passenger airline deregulation in the USA).

Source: Air Transport Association – www.air-transport.org

2.1.1.2. Airlines and Airports

Over the years airlines, and even some airports, started to lose their national character and entered a process of internationalization. Airlines, once the proud representation of a nation, may now be privately owned and conglomerated in big international groups, like Air France-KLM, which integrate not only the French and Dutch national carriers, but a myriad of other companies like the Irish CityJet or the Belgian VLM Airlines.³

Even when not integrated in a large group, companies now tend to form large airline alliances, like Skyteam, Star Alliance and Oneworld, which are nothing more than agreements of several airlines at various levels, providing a network of connectivity and convenience for international passengers, while allowing companies to reduce costs, by reducing overcapacity and integrating sales offices. This arrangement also allowed companies to increase their possible network without major investments and increased their power while negotiating with airports.

¹ Mainly because it involved many countries, some of them with bilateral agreements, and each one with its own regulatory framework.

² And others outside the EU, like Norway.

³ They also have minor participations in other companies, like Alitalia or Royal Air Maroc.

Airlines' use of airports has also changed: the traditional point-to-point operations, where airlines offered connections between pair of cities, have now changed to hub-and-spoke operations,⁴ where an airline has a central hub where most of their flights go to. This scheme allows an increase in the number of connections between groups of cities (Figure 2.2. provides an example for a group of 5 cities).

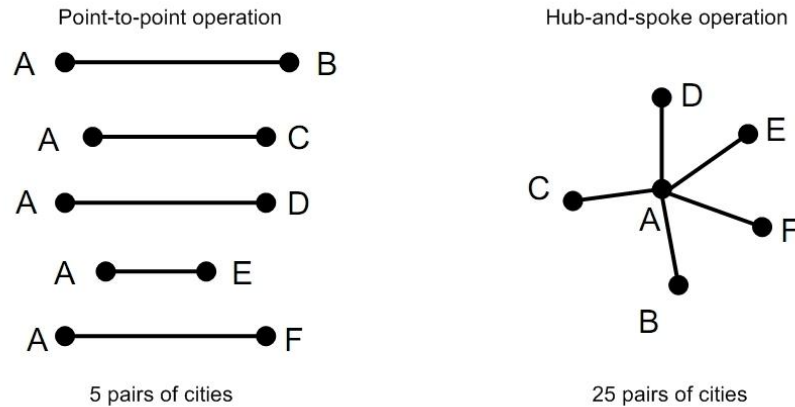


Fig. 2.2. – Point-to-point and hub-and-spoke operations.

With this new type of operations some airports became huge hub terminals, with tens of millions of passengers (MPax) every year, many of them only transfer passengers, i.e., passengers whose final destination is not that airport. Atlanta, in the USA, with more than 90 MPax in 2008, and in Europe, London's Heathrow, with more than 67 MPax, and Paris' Charles de Gaulle, with more than 60 MPax, are good examples of those large hub infrastructures that appeared in the last few decades. Trying to become a hub for an airline, with the consequently increase in the number of passengers and revenues, airports started to compete between each other.

In technological terms airports remain essentially the same: passengers arrive at the airport, go to a check-in counter (which can be self-service now, or can even be done at home in some cases), leave their bags, go to the security check (greatly improved since the 9/11 attacks), and walk to a plane. In more than 50 years, some technological improvements were introduced (like the mentioned self-service check-in counters or the automatic luggage sorting system), but essential functions and requirements, in terms of engineering, of an airport did not change in a drastic way (Neufville, 2008).

Now, as then, an airport is a mean of connecting different modes of transportation: passengers (and cargo) arrive by land and depart by air, or vice-versa.

It is normally considered that airports offer services, to passengers and airlines, in three main areas: landside, airside and also air traffic control.

Traffic control is under strict supervision by external entities and is of extreme importance, since the safety of aircraft and passengers, while in flight and during take-off and landing procedures, depends from it.

Airside services are the ones offered to the airlines, and include runways, taxiways (circulation areas for planes), parking spaces, access to boarding/unboarding gates, etc. Airside services also include

⁴ This is mainly true for flagship (or legacy) carriers. LCC, with a few exceptions, normally use the point-to-point system.

security facilities in case of incidents (firemen), and other services like catering, cleaning, and refueling.

Parking spaces, public transport stations, and access to the airport in general are all included in the landside services. Terminals, with all their facilities, like check-in counters, security checks, customs, and duty-free shops, are also part of the landside services an airport provides to their customers.

Since so many people use them, airports realized that they did not need to be only an infrastructure for boarding and unboarding passengers efficiently, but also a place where a lot of business opportunities arise, which can lead to more profitable activities.

Figure 2.3. summarizes the services that are available for inbound passengers, outbound passengers, and airlines in an airport. On the top half of Figure 2.3. are listed services that are normally under the responsibility of airport authorities. Services that can be outsourced to other companies (public, private or even airlines), with the airport receiving a rent, are listed on the other half.

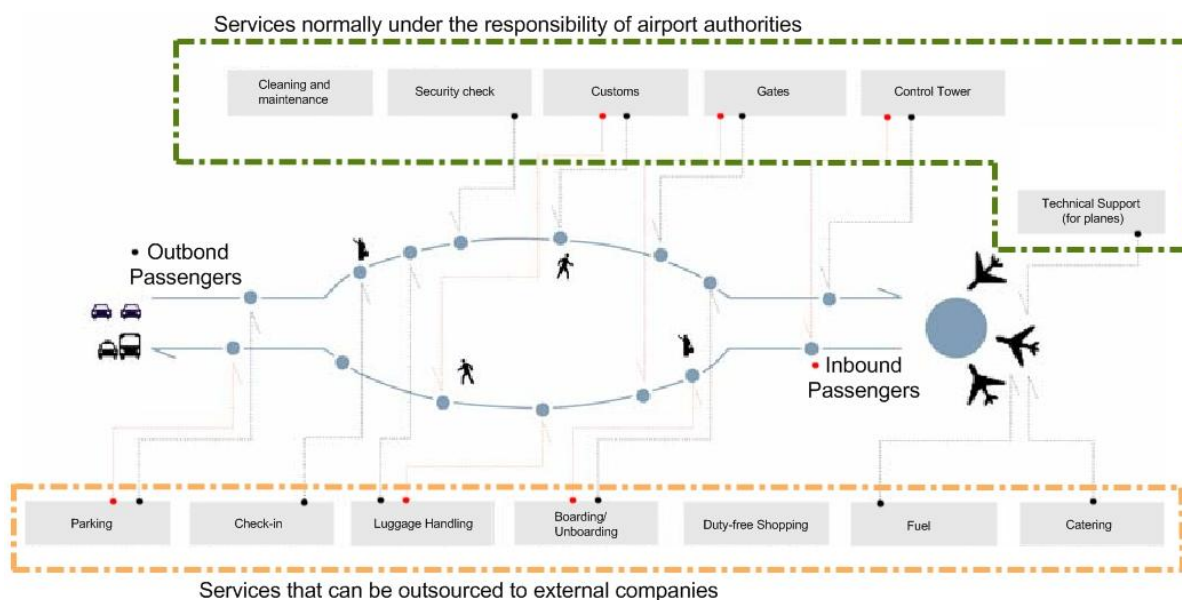


Fig. 2.3. – Services offered by an airport.

Source: Adapted from CEGEA and TRENMO (2007)

2.1.1.3. The Appearance of the Low-Cost Carriers

The first LCC, Southwest Airlines, started its operations in the USA in the 1970's, with a business model which was very different from *traditional* airlines. The definition of what really is a LCC remains a little dubious, but according to Neufville (2007), a LCC can be defined as a company where the cost of moving one passenger-seat for one mile (*cost per seat-mile*) is in the lower end of the industry's average.⁵

Ryanair and EasyJet in Europe and Southwest, jetBlue, Spirit, and Westjet in North America are just a few examples of companies that fit in this classification (Neufville, 2007).

The basic business model of LCCs (with some specific traits of every airline) is to offer basic travel packages (sometimes the ticket includes only the right to have a seat on the plane) at the lowest cost

⁵ This *cost per seat-mile* is simply a unit of production and does not consider whether the seat is actually sold or not.

possible. To reduce costs they operate only in point-to-point schemes (which brings benefits to customers because it allows them to make less time consuming trips), in routes where there is high density of traffic and between cities that make possible relatively short time travels (2-3 hours maximum). To reduce maintenance costs, their fleet is normally composed of only one type of aircraft.

Other ways of reducing costs include avoiding highly congested airports, that normally have higher turn-around times (the time a plane take to land and then depart again with new passengers onboard) and more congested air space around the airport (with the consequently delays while waiting for clearance to land or take-off). Using this kind of airports allows LCCs to achieve higher productivity from their aircrafts, minimizing unproductive time either on the ground or in the air.

If they choose to operate in more congested airports (which they will, if they consider that the market opportunities outweigh the disadvantages of using a congested space) they tend to rent the least expensive ground facilities (normally the older ones available at an airport) and use them much more intensely than other air carriers. The combined result of using cheaper facilities, with higher productivity (jetBlue moves three times more passengers per year at their JFK Airport's gates in New York City than American Airlines in the exact same airport), means that even if LCCs fly to the same airport than a flagship airline they can sell less expensive tickets to their customers than flagship carriers (Neufville, 2006).

Although business people (which tend to be the most valuable customers of an airline) start to assume an important role among LCCs users, their main customers continue to be tourists or leisure travelers that seek not high quality service and superfluous "luxuries" like onboard snacks, but simply a way of getting to their destination in the cheapest way possible, within certain time boundaries.

With these aggressive tactics LCC managed to keep growth rates over recent years much higher than the sector's average,⁶ which allowed them to rapidly increase their market share and, consequently, their influence in the industry.

Although existing airlines suffered a great deal with the appearance and growth of LCCs, they were not the only ones affected by their appearance. Airports also suffered the effects of these new players in the business, with their new needs and demands.

In major metropolitan areas, LCCs started to use secondary airports or old reconverted military fields, which before them were empty or almost abandoned. This kind of facilities offered low prices and could be easily (and cheaply) converted for LCCs' needs. This meant that large international airports that had a monopoly in air traffic in a given metropolitan area started to lose their market share (Neufville, 2007), which introduced a new uncertainty that most airports were not used to: real competition from nearby airports.

This meant that airports could no longer depend on location alone to provide traffic (secondary airports are normally farther away from city centers). Evidence shows that passengers are willing to spend more time reaching city center if that means they can get lower air fares (Chambers, 2005).

By revitalizing so many secondary airports, LCCs have gained a bargaining position never seen before in the industry: just the threat of switching to another airport is most of the times enough to ensure that LCCs are given conditions (new terminals or a reduction in fares, for example) that otherwise would not exist.

⁶ For example, Ryanair came from 2,2 MPax in 1995 to 40,5 MPax in 2006, and Easyjet from 0,03 MPax to 33 MPax in the same period (Chambers, 2005).

Since LCCs require new kinds of services from an airport, if an airport wants to receive this kind of airlines it must adapt their offer for their needs.

Fancy, expensive, terminals, that are architectural landmarks of their time, do not appeal to LCCs. Instead, they want cheap, low tech facilities that are just enough to fit their needs. Therefore, airports hoping to serve low-cost passengers, must offer simple terminals, rapid check-in procedures, functional catering facilities in order to both attract the low-cost customer, and to provide time for these customer to purchase goods (Chambers, 2005).

Table 2.2. summarizes the main differences in what a LCC and a legacy carrier require from an airport.

Table 2.2. – Differences between LCCs and legacy carriers requirements in an airport.

Source: Adapted from Pitt (2001)

Low-cost carrier	Legacy carrier
<i>Access</i>	
Location of secondary importance. Rail links not necessary.	Convenient location essential to service, particularly for non-economy passengers
<i>Terminal</i>	
No need for ticketing area (if needed, a very small one is enough)	High profile ticketing desk reflecting corporate image and presence
Fast check-in, control of speed essential	Check-in convenience and profile is of great importance
Terminal services (food, etc.) are secondary	Important that passengers feel purchasing needs are met
Terminal facilities not important	Image of major international hub with good facilities is preferable
<i>Gate</i>	
Low tech gate facilities (comfort of secondary importance)	High tech gate facilities, creating professional/polished image
Power in and out of gate (eliminating wasting push back time)	Air-bridge essential to product image wherever possible
Economy lounges facilities only	Business and first class lounges required
<i>General</i>	
Minimal catering facilities required	Facilities for preparation of in flight food essential as forms part of flight package
Cleaning staff required less frequently	Aircraft cleanliness essential part of package
No standby aircraft parking during daytime	Standby aircraft require parking
Efficient removal and loading of aircraft baggage	Efficient delivery of arriving baggage is priority

2.1.2. TRADITIONAL AIRPORT PLANNING

Regarding airport design, the common practice was – and still is – to make a master plan,⁷ which encompasses such aspects as the airport's size, layout, costs, and financial feasibility.

A master plan can be described as *a plan for the airport construction that considers the possibilities of maximum development of the airport in the given locality. The master plan of an airport may be elaborated for an existing airport as well as for an entirely new one, regardless of the size of the airport* (Kazda, Caves, 2007).

In essence, a master plan is a document that represents how the airport development should be undertaken in order to meet the foreseen demand while maximizing and preserving the ultimate capacity of the site (it is necessary to assess the capacity of each airport system individually).

This approach, sanctioned, among others, by the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA), has two main phases, namely, the determination of the correct forecast, and the selection of a single plan that is best suited for this forecast. The main problem of this approach resides in the former: choosing one, and only one, *correct* forecast, leads to inflexible frameworks for the development of airports. The assumption that airport planners – or anyone else, for that matter – can correctly anticipate the future might have been truer in the past, but is no longer the case, and new design paradigms should be used to maximize profits (Neufville, 2008).

2.2. THE VALUE OF FLEXIBILITY

2.2.1. FORECASTS ARE ALWAYS WRONG

A major problem with the elaboration of master plans for the development of an airport is their dependence on forecasts. While forecasts for short-time periods may reveal to be close to reality, experience shows that, for longer time periods, actual levels of traffic are far from what was predicted (Neufville, 2007). For example, half of the five-year forecasts for individual airports in the USA have been off by 10 percent (Neufville, 2008).

Tables A.2. and A.3., in the appendices, represent other examples of differences between traffic forecasts and actual traffic for Lisbon Airport (Table A.2.) and for American domestic flights (Table A.3.).

Since forecasting is essentially an estimation of the future based on past trends, the occurrence of *trend-breakers*, which provoke sudden shifts in traffic patterns, makes forecasting an uncertain science. These *trend-breakers* might include such diverse events as (Neufville, 2007):

- Technological revolutions, like the introduction of Geographic Positioning Systems (GPS) that reduced the cost of air traffic control and ground radars;
- Changes in the industry, like merges of major airlines such as Air France and KLM;
- Economic and financial disrupters, like worldwide recessions or the bankruptcy of major airlines;
- Political events, like the opening of China into world trade and the boom of inexpensive tourism in Asia;
- Health crisis, like SARS, or the swine and avian *influenza* outbreaks;
- Natural catastrophes, like the Asian tsunami in 2004;
- Peaks in energy (namely oil) prices, like in 1973 and 2008;

⁷ Appendix A.1. presents the mains purposes of an airport's master plan, as defined by ICAO.

- Wars (like both Gulf Wars) or terrorist attacks (like the 9/11 attacks on US territory).

Combined with the effect of the already mentioned deregulation and appearance of LCCs, these *trend-breakers* make the future even more volatile. As a consequence, forecasting, even at short terms, may become unreliable.

A new paradigm is then needed in order to appraise and take advantage of the situation the aviation industry now faces.

2.2.2. FLEXIBLE DESIGN – TAKING ADVANTAGE OF UNCERTAINTY

The traditional method of designing complex engineering systems (being the airport master plan just an example), too often focus on a deterministic view of the environment in which the system operates. In an uncertain world, flexibility is a major addition to increase the chances of having a successful project. By acting proactively, it can take advantage of unexpected upside opportunities, while reducing exposure to downside risks (Cardin, Neufville, 2008).

Some of the risks such a project faces, and how they should be quantified, are presented in Table 2.3.

Table 2.3. – Risks, uncertainties and data sources for a project.
Source: Adapted from Greden *et al.* (2005)

Risk Class	Uncertainties	Data source or means of quantification
Market	- Demand for service	- Historical data (if available)
	- Demand as a function of system's environmental structure	- Expert opinion
	- Energy prices	- Simulation model of system performance
Technological	- Success or failure of a new technology	- Expert opinion
	- Introduction of new or superior technology	- Simulation model of system performance
		- Stochastic models
Future use	- Capacity of system to respond to changes in service type or intensity	- Expert opinion
	- Rate of need for change	- Historical data
Regulatory	- Introducing new standards for existing facilities	- Expert information and opinion

Also, according to Lin (2008), uncertainty can be of various types, divided into two main groups:

- Lack of knowledge and lack of definition, which can be addressed by spending effort on acquiring more information to clarify the ambiguity;
- Statistically characterized variables, known unknowns and unknown unknowns form the other group of irreducible uncertainties, which will only be resolved by waiting for the occurrence of future events.

To deal with that uncertainty, a framework with some basic key concepts was also cited by Lin (2008):

- Uncertainties are things that are not known (or known with imprecision), thus they can lead to risk but also to opportunity – they are risk neutral;
- Mitigations are technical approaches to risk minimization while exploitations are efforts to capture and enhance opportunities;
- Outcomes are attributes of the systems to cope with uncertainty, such as reliability, robustness, versatility or flexibility.

Flexibility is especially valuable for the most uncertain projects (if there were no uncertainty associated with a project there would be no point in having contingency plans or insurance) and aims to improve their overall value. It is thus especially valuable for major, unique, and long-term investments – where they are subjected to more prominent uncertainties and, therefore, future prospects are more difficult to predict.

This kind of investments are also more likely to be important at a political level, and thus sensitive to changes to the political orientation of the ruling powers, which can affect how they are used, creating new levels of exogenous uncertainty, in addition to all the uncertainties the sector already faces endogenously (Figure 2.4.).

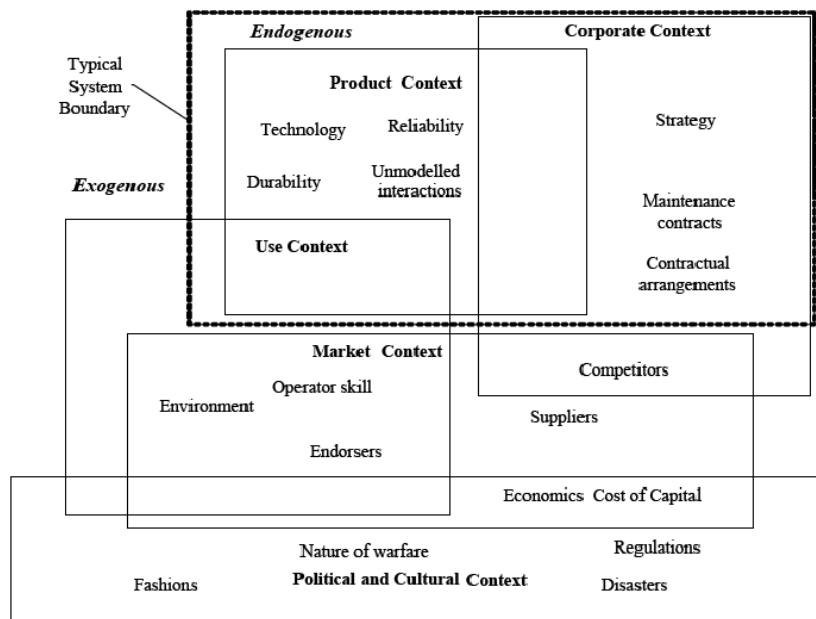


Fig. 2.4. – Sources of uncertainty and their contexts.

Source: Lin (2008)

Flexibility differs from other classes of assets in the way risk is managed. Indeed, the general rule is, the greater the risk, the less something is worth. The situation is just the opposite for flexible assets. This particular feature is due to the hockey-stick value of flexibility (Figure 2.5.). Because the value of the flexibility is either zero (if flexible outcomes are not pursued) or something, the positive values are not cancelled out by the zero values. Events that are furthest from the trend, give the highest value (Neufville, Scholtes, 2006).

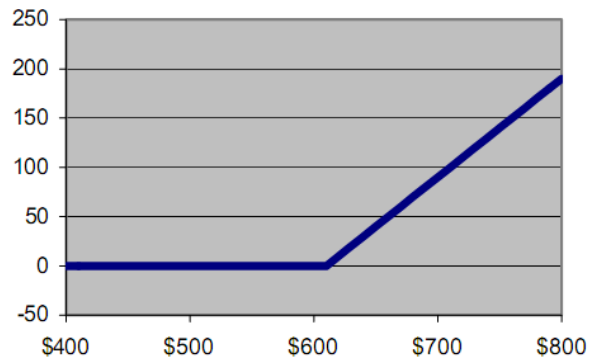


Fig. 2.5. – Example of the hockey-stick value of flexibility.
Source: Adapted from Neufville and Scholtes (2006)

Planners (of airports, or of others engineering systems) should be act proactively in enabling the possible futures, without making, unnecessary, premature and irrevocable commitments to particular structures or states of the system. This will allow them to react to changing circumstances and adapt their systems to the new, unpredicted, reality.

As Table 2.4. shows, this new paradigm differs from the old ways in a considerable manner.

Table 2.4. – Old and new paradigm for project development.
Source: Adapted from Neufville and Scholtes (2006)

Process	Traditional results of the process	New results of the process, after considering flexibility
Definition of requirements	Specifications that design must meet	A range of forecasts or scenarios, and corresponding possible needs
Design of project	A best design	An initial design that can adapt flexibly to scenario and needs to develop
Project appraisal	The value of the project	Appraisal of the project including the option value of the design flexibility
Implementation	Delivery of project according to plan	Monitoring of conditions and adapting the initial design as fits the actual scenario

3

STANDARD VALUATION MODELS

3.1. DISCOUNTED CASH FLOW

To assess the value of an investment, a basic principle in finance – the time value of money – must be taken into account: *a dollar today is worth more than a dollar tomorrow*, since the dollar today can be invested to start earning interest immediately (Brealey, Myers, 2000). With that principle in mind it is easy to understand that future cash flows will not worth as much as present cash flows, and before committing to a project one should know the relationship between a dollar today, and a (possibly uncertain) dollar in the future (Ross *et al.*, 1999).

This issue is especially important in projects that evolve over a long period of time, as is the case of large engineering systems. To evaluate if a project should be undertaken or not, it is necessary to compare benefits and costs that occur at different moments in time, i.e., the determination of whether the tangible value of the project outputs will be enough to account for financial obligations such as amortizations of loans, operation and maintenance costs, interests, etc.

3.1.1. NET PRESENT VALUE

3.1.1.1. Mathematical Formulation

To evaluate the value of a project in *today's* money, it has been common to use the figure of net present value (NPV), which is nothing more than the sum of all project cash flows, present and future (which are assumed to be static and predetermined throughout the life span of the project), adjusted to present value, deducted from the investments initially made (3.1). Typically, a large negative cash flow occurs at the beginning of the project (at $i = 0$), when the large initial investment is made.

$$NPV = C_0 + \sum_{i=1}^n \frac{C_i}{(1+r)^i} \quad (3.1)$$

Where,

C_0 : cash flow at time zero (it is usually considered as the initial investment)

C_i : cash flow at time i

r : discount rate

n : life of the project

3.1.1.2. The Decision-Making Process

After applying an appropriate market discount rate to every future cash flow – which will reduce the value of the cash flow to present value terms – it is possible to estimate the net present value (NPV) of the project. If NPV is positive, the project is expected to create economic value, and therefore increase the wealth of project owners and should be undertaken. If negative, the project should be abandoned, since it will reduce the value of the company. When choosing among a set of projects, the NPV criterion dictates that managers opt for the project with the highest NPV, since more favourable projects have a higher NPV than less favourable ones.

This technique is mathematically and computationally simple (most modern spreadsheets include it as a standard function) but, most importantly, reduces financial and economical information about the project to a single value for the ease of decision-making. A few advantages of using NPV were compiled by Maseda (2008):

- Clear, consistent decision criteria for all projects;
- Same results regardless of risk preferences of investors;
- Quantitative, decent level of precision, and economically rational;
- Not as vulnerable to accounting conventions (depreciation, investing, valuation and, so forth);
- Relatively simple, widely taught, and widely accepted;
- Simple to explain to management: “If benefits outweigh the costs, do it!”.

3.1.1.3. Relevant Cash Flows

The choice of which cash flows to use in NPV valuation is critical: only cash flows that are *incremental* to a project should be used. These cash flows are the changes in the firm’s cash flow that occur as a direct consequence of accepting the project, i.e., cash flows that occur only if the project is accepted (Ross *et al.*, 1999)

Sunk costs – costs that have occurred in the past – should not be included since they cannot be changed by the decision to accept or reject the project: they are not incremental cash flows.

On the other hand, opportunity costs and side effects should be taken into account when estimating cash flows.

Opportunity costs are the costs of lost options, i.e., the value of the next best alternative foregone as the result of making a decision. For example, if a company has an asset that can be used in various projects, but assigns it to a certain project, the potential revenues from other potential uses are lost. By taking the project, the firm forgoes other opportunities for using the assets.

Side effects are the effects of a proposed project on other parts of the firm. A positive side effect occurs when there are benefits to those other parts, and a negative side effect occurs when there are costs to other projects, like the transfer of cash flows to a new project from customers and sales of others projects of the firm (a phenomenon known as *erosion*).

Other relevant cash flows include, changes in net working capital,⁸ financing costs, taxes, depreciation, capital expenditures (CAPEX), inflation, etc.

⁸ An investment in net working capital – the operating liquidity available to a business – arises whenever (1) raw materials and other inventory are purchased prior to the sale of finished goods, (2) cash is kept in the project as a buffer against unexpected expenditures, and (3) credit sales are made, generating accounts receivable rather than cash. This invest-

3.1.2. WEIGHTED AVERAGE COST OF CAPITAL

A critical component of this type of valuation is the choice of an accurate discount rate, which represents the investor's minimum acceptable return from choosing to invest in the present rather than at some point in the future.

This discount rate should, at least in theory, equal the rate of return of equivalent investment alternatives in the capital market (Ramírez, 2002).

Typically the rate has been chosen by application of the free cash flow model (FCF), which, in the case of a company that not only uses equity, but also debt, estimates the discount rate using the weighted average cost of capital (WACC) (3.2), which represents the weighted average of the returns required by providers of debt and equity finance to a company.

$$WACC = K_E \times (1 - g) + K_D \times (1 - t) \times g \quad (3.2)$$

Where,

K_E : cost of equity

K_D : cost of debt (pre-tax)

g : level of financial leverage, measured by the Debt-to-Total-Assets ratio

t : corporate tax

3.1.3. COST OF DEBT AND COST OF EQUITY

The cost of debt (K_D) is estimated adding the risk-free rate (r_F) – since there are no portfolios of securities that have no default risk, the risk-free rate used is the yield-to-maturity of a Treasury bond with a maturity similar to the economic useful life of the project – to a spread that reflects the market price for credit risk. This premium is either measured directly from the yield of a company's bond or through comparator information (Alexander *et al.*, 1999).

The cost of equity (K_E) can be estimated using the Capital Asset Pricing Model (CAPM), which assumes⁹ that anyone holding a risky security will demand a proportional return in excess in contrast to the return they would receive from a risk-free security, and the additional return is proportional to the amount of risk faced.

Since the CAPM assumes investors are fully diversified, only the systematic risk – the uncertainty of future returns due to factors that affect the market as a whole, like inflation, GDP growth or interest rates – is relevant to its calculation. Unsystematic risk, which accounts the uncertainty in future returns due to characteristics of the industry or the individual company, is not relevant because it can be diversified away, as long investors choose to invest in a suitably wide portfolio, where investments that perform well, and those that perform badly due to specific risk factors tend to cancel each other (Collins, 2001).

ment in net working capital represents a cash outflow, because cash generated elsewhere in the firm is tied up in the project (Ross *et al.*, 1999).

⁹ The assumptions of this model are presented in chapter A.3. of the appendices.

CAPM is the most widely used model to determine the cost of equity and is mathematically simple to use (3.3):

$$K_E = r_F + \beta_E \times (r_M - r_F) \quad (3.3)$$

Where,

r_F : risk-free rate

β_E : equity beta

r_M : level of market return

$(r_M - r_F)$: market risk premium

Equation 3.3 can be represented graphically (Figure 3.1.). The straight line represented in blue is called the security market line and indicates the expected risk-adjusted rate of return for an investment linearly correlates with the market risk components (β_E) which represents the sensitivity of the asset returns to market returns (Hodota, 2006). The slope of the line is the market risk premium and the intersection with the vertical axis is the risk-free rate. Being a risky asset, theory suggests that the market portfolio (when β_E equals one) is above the risk-free rate (Ross *et al.*, 1999)

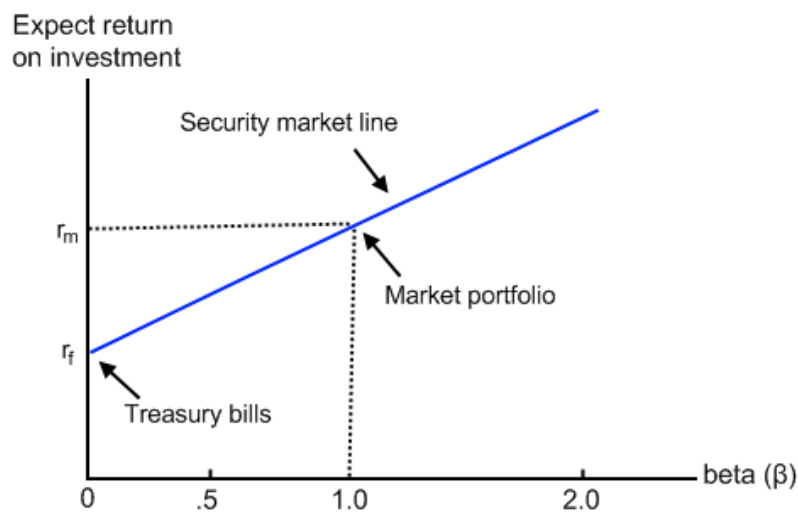


Fig. 3.1. – Security market line.

Source: Adapted from Brealey and Myers (2000)

The market risk premium is the level of return that investors expect to achieve when holding risky securities, over investing in risk-free assets.

The equity beta is the price of the project's systematic risk compared to the whole economy (which has a beta equal to one), and it is the only company specific element to be established. In companies traded in the stock market, assessing its value is very simple (3.4), and it is usually done during a pe-

riod of three or five years. In others assets not publicly traded, like airports and other infrastructures, calculating it might be more difficult and more prone to misestimation.

The beta of the market as a whole equals one. If its value is lower than one, than the asset being analyzed has a systematic risk that is lower than the market average, investors then require lower returns from that portfolio and discount rates become lower. The opposite happens when its value is higher than one: in that case the asset has a systematic risk higher than the market as a whole.

$$\beta_E = \frac{Cov(r_E, r_M)}{Var(r_E)} \quad (3.4)$$

Where,

r_E : rate of return of the company

r_M : level of market return

$Cov(r_E, r_M)$: covariance between the rates of return of the company and the market as a whole

$Var(r_E)$: variance of the rate of return of the asset

The cost of debt is multiplied by $(1 - t)$ in equation 3.2 because interest is tax-deductible at the corporate level. However, the cost of equity is not multiplied by this factor because dividends are not deductible (Ross *et al.*, 1999)

3.2. FREE CASH FLOW VS. CAPITAL CASH FLOW

Although being constantly used when valuating risky cash flows, the FCF model should be used in projects with a relatively low level of financial leverage and with a capital structure that remains essentially the same during the life of the project. When this conditions do not verify, the application of FCF methodologies might even reveal to be inadequate (Coutinho dos Santos, Pinto, 2008).

Clearly, that is not the case of large transport infrastructures like an airport.

For projects with high levels of financial leverage and/or variable capital structure, the Capital Cash Flow (CCF) model (Ruback, 2002), addresses these problems by treating debt tax shields differently. In the FCF model, the debt tax shields are disregarded in the estimation of cash flows and incorporated in the calculation of the WACC (if CAPM is used). On the other hand, in the CCF model the risk-adjusted discount rate is calculated before taxes, and the debt tax shields are a relevant cash flow.

The appropriate discount rate to value CCFs is a before-tax rate because the tax benefits of debt financing are included in the CCFs. That said, the before-tax rate should correspond to the riskiness of the cash flows, and is the expected asset return (K_A) (3.5):¹⁰

¹⁰ In his paper, Ruback (2002) shows that K_A is equivalent to WACC, equation (3.2), before taxes, i.e., equation (3.2) without the $(1 - t)$ parameter.

$$K_A = r_F + \beta_A \times (r_M - r_F) \quad (3.5)$$

Where,

r_F : risk-free rate

β_A : asset beta

r_M : level of market return

$(r_M - r_F)$: market risk premium

Asset beta can be related to equity beta and debt beta by equation 3.6:

$$\beta_A = \beta_D \times g + \beta_E \times (1-g) \quad (3.6)$$

Where,

β_A : asset beta

β_D : debt beta

β_E : equity beta

g : level of financial leverage

Since $\beta_D \times g$ can normally be considered null, asset beta can be estimated by equation 3.7:

$$\beta_A = \beta_E \times (1-g) \quad (3.7)$$

With this model it is possible to avoid the estimation of the level of financial leverage of the project (a necessary step in the FCF model), normally a difficult task in projects with long duration like an airport, in which the level of financial leverage is always changing (Coutinho dos Santos, Pinto, 2008).

In the model used in this research, both FCF and CCF models will be used in order to allow comparisons between them.

3.3. THE DISCOUNTED CASH FLOW MODELS SHORTCOMINGS

The DCF models, explained in the preceding chapters, make a number of assumptions that sometimes do not apply to the real economy and are often overlooked (Table 3.1.). For example, it assumes one of two things: either the investment is *reversible* and can be undone (and the expenditures are recovered) if the market conditions are worst than anticipated or the investment is *irreversible*, i.e., the initial cost of investment is at least partially sunk and cannot be recovered, and then the company will have to decide to take the investment now or will lose the opportunity to do it in the future (Dixit, Pindyck, 1994 and Dixit, Pindyck, 1995).

In those models, cash flows are assumed to follow a deterministic path into a distant future, with no management intervention when market conditions change, and the risk associated with the project is accounted in the discount rate, which is subjected to discussion on how to be correctly assessed (Mittal, 2004). If a project involves high uncertainty, a high discount rate is used in order to reflect a high-risk premium.

Although deterministic cash flows into the future may be true for some projects, clearly that is not the case of a large transportation system like an airport, where the estimation of future cash flows is very difficult and subjected to traffic forecasting and so, management has a very important role in deciding whether investments should be undertaken, postponed or even cancelled.

When a project has flexible components, the use of NPV systematically underestimates its value.

In short, the DCF procedures fail – when applied to systems operating in an uncertain environment – to recognize that effective management of the risks enhances the value of the system. Put another way, the DCF models are adequate over a limited range that does not include major technological investments operating in the midst of considerable technological and market uncertainties (Neufville, 2003), but can be used for decisions involving a moderately straightforward business, unsophisticated projects, and a steady environment that allows for dependable forecasts (Miller, Park, 2002). In situations where uncertainty plays a major role and where management decisions during the life of the project are important, using DCF can lead to questionable decisions.

A comparison between DCF assumptions and the reality is presented in Table 3.1.

Table 3.1. – Disadvantages of DCF models: assumptions vs. reality.
Source: Mittal (2004)

DCF assumptions	Reality
Decisions are made now and cash flow streams are fixes for future.	Uncertainty and variability in future outcomes. Not all decisions are made today, as some may be deferred to the future, when uncertainty is resolved.
Once launched, all projects are passively managed.	Projects are usually actively managed throughout the project life-cycle, including check-points, decision options, budget constraints, etc.
Future free cash flows are all highly predictable and deterministic.	It may be difficult to estimate future cash flows as they are usually stochastic and risky in nature.
Project discount rate used is the opportunity cost of capital, which is proportional to non-diversifiable risk.	There are multiple sources of business risk with different characteristics, and some are diversifiable across projects or time.
All risks are completely accounted for by the constant discount rate.	Project risk can change during the course of time.
All factors that could affect the outcome of the project are reflected in NPV.	Project complexity and so-called externalities make it difficult to quantify all factors in terms of incremental cash flows. Disrupted, unplanned outcomes can be significant and strategically important.
Unknown, intangible or immeasurable factors are valued at zero.	Many important benefits may be intangible assets or qualitative strategic positions.

4

OPTIONS

4.1. FINANCIAL OPTIONS

In a stock market, an *option* is *the right, but not the obligation* to buy (a call option) or sell (a put option) a specific quantity of an asset at a fixed price (the *strike* or *exercise* price) at or before the expiration date of the option.¹¹ To have the option to buy or sell the asset the buyer pays a price (the *option price* or *value*).

This option will only be exercised if the price of the asset is below the strike price, in case of a call option, or if the price of the asset is greater than the strike price, in case of a put option. Otherwise, the holder of the option will let the expiration date pass and the option will expire, without any loss besides the option price (Damodaran, 2000).

4.1.1. VALUATION MODELS

4.1.1.1. Black-Scholes Model

The first attempt to assess the value of an option was undertaken in the beginning of the 20th Century by the French mathematician Louis Bachelier (Merton, 1973). Since then, a wide range of mathematicians and economists have contributed to the theory of option pricing.

Since 1973, with the publishing of the seminal work of Black and Scholes – with contributions, in the same year, of Robert Merton, who shared a Nobel Memorial Prize in Economic Sciences with Scholes in 1997¹² – the value of a European option could be estimated with a much more robust theoretical framework.

Black and Scholes proposed a continuous-time model, which consisted in an analytical solution to solve a partial differential equation with five variables.¹³

¹¹ An option which can only be exercised at the time of expiration is called a *European option*. One than can be exercised at any time up to and including the time of expiration is called an *American option*.

¹² Fischer Black was not eligible for the prize since he had died in 1995.

¹³ A sixth variable was added to the original model by Merton (1973): dividends paid on the underlying asset, y = dividends/current value of the asset.

Those variables are (Damodaran, 2008):

- Current value of the underlying asset, S
- Variance in value of the underlying asset, σ^2
- Strike price of option, K
- Time to expiration of option, t
- Riskless interest rate corresponding to life of option, r

From those five parameters four of them are observable – only variance in value of the underlying asset must be estimated – which makes this formula highly attractable. This attraction comes also from the parameters that are not needed, namely the investor's willingness to bear risk and its independence from the value of the stock (Ross *et al.*, 1999).

Another source of attraction of this model comes from its relative simpleness: the estimation of the value of any European option¹⁴ use only a small number of inputs. Additionally, it has been shown to be remarkably robust in valuing many listed options (Damodaran, 2001).

The way each of these variables affects the value of call and put prices is presented in Table 4.1.

Table 4.1. – Variables affecting call and put prices.
Source: Damodaran (2008)

Factor	Effect on call value	Effect on put value
Increase in underlying asset's value	Increases	Decreases
Increase in strike price	Decreases	Increases
Increase in variance of underlying asset	Increases	Increases
Increase in time to expiration	Increases	Increases
Increase in interest rates	Increases	Decreases
Increase in dividends paid	Decreases	Increases

The value of a call option is given by equation 4.1:

$$\text{Value of a call} = S \times N(d_1) - K \times e^{-rt} \times N(d_2) \quad (4.1)$$

Where d_1 and d_2 are given by equations 4.2 and 4.3, being $N(d)$ a cumulative normal probability function:

$$d_1 = \frac{\ln\left(\frac{S}{K}\right) + \left(r + \frac{\sigma^2}{2}\right)t}{\sigma\sqrt{t}} \quad (4.2)$$

$$d_2 = d_1 - \sigma\sqrt{t} \quad (4.3)$$

¹⁴ Other assumptions of the model are presented in appendix A.4.

To value a European put option, the parameter S is multiplied by -1 (Amram, Kulatilaka, 1999).

If the underlying asset pays dividends its value is reduced, consequently call options will become less valuable and put options more valuable as expected dividend payment increases. Damodaran (2001) proposes a way to deal with the dividend paid in the Black-Scholes (BS) model, if it remains unchanged during the life of the option. Adding the dividend to this calculation affects the value of both the call (4.4) and d_1 (4.5). The value of d_2 remains unchanged.

$$\text{Value of a call} = S \times e^{-yt} \times N(d_1) - K \times e^{-rt} \times N(d_2) \quad (4.4)$$

$$d_1 = \frac{\ln\left(\frac{S}{K}\right) + \left(r - y + \frac{\sigma^2}{2}\right)t}{\sigma\sqrt{t}} \quad (4.5)$$

These adjustments have two effects, resulting in a reduction in the value of the calls estimated using this model (Damodaran, 2001):

- The value of the asset is discounted back to the present at the dividend yield to take into account the expected drop in asset value resulting from dividend payments;
- The interest rate is offset by the dividend yield to reflect the lower carrying cost from holding the asset.

4.1.1.2. Binomial Lattices

A few years later after the publication of the paper by Black and Scholes, Cox *et al.* (1979) proposed a discrete-time model, based on binomial lattices, that required only elementary mathematics, yet it contains as a special limiting case the Black-Scholes model. This approach can also be used to solve for the value of early-exercise American option, whereas the Black-Scholes model can only value European options (Hahn, Dyer, 2008).

This model assumes that the asset price in a given period can only increase by a fixed factor (u) or decrease by another fixed factor (d). This makes the lattice recombine at each node (Figure 4.1.), which means an upward movement followed by a downward one leads to the same result as a downward movement followed by an upward one (Chambers, 2005). Another important consequence of this recombination is that there are only $n + 1$ nodes at any period n , a significant property for reducing the computational time required for solving this sort of problems. If the movements did not recombine at each period, the possible outcomes would grow exponentially, by a factor of 2^n . In the case of the model developed by the author, with its 50 periods (excluding the initial state), that would mean a total of $1,13 \times 10^{15}$ outcomes, instead of 51.

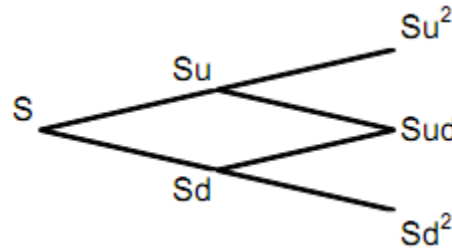


Fig. 4.1. – Initial stages of a binomial lattice.

Source: Carvalho (2005)

With this model it is also possible to determine the probability of each outcome, being p the probability increase factor, and $(1 - p)$ the probability decrease factor (4.6) (Dixit, Pindyck, 1994):

$$p = \frac{1}{2} + \frac{1}{2} \times \left(\frac{v}{\sigma} \right) \times \sqrt{\Delta t} \quad (4.6)$$

Where,

v : average growth rate (%)

σ : standard deviation (%)

Δt : length of each period

The increase and decrease factors can be determined using equations 4.7 and 4.8, respectively:

$$u = e^{\sigma \sqrt{\Delta t}} \quad (4.7)$$

$$d = \frac{1}{u} = e^{-\sigma \sqrt{\Delta t}} \quad (4.8)$$

The main advantages of using a binomial lattice instead of the BS model are its intuitive valuation procedure and the flexible valuation process. It also provides a visual aid, since the decision-maker can observe option values throughout the lattice (Miller, Park, 2002).

4.1.1.3. Simulations

When a model is too complex to be valued by others methods, a simulation running random possible various outcomes can be executed. Instead of making the computer calculate all possible outcomes in a binomial lattice (when that is possible), one can simply ask the computer to sample a large number of paths, compute the asset value on each path, and then take the average of those asset prices (Ross *et al.*, 1999).

The kind of simulations normally used when valuing options are *Monte Carlo*¹⁵ simulations, developed by scientists working on nuclear weapons in Los Alamos after WWII (Metropolis, Ulam,

¹⁵ The term *Monte Carlo* is a reference to the gambling – and its random results – at the casinos in the Mediterranean city of Monte Carlo, Monaco.

1949).¹⁶ Monte Carlo methods are a class of computational algorithms that rely on repeated random sampling to compute their results and are especially useful in studying systems with a large number of coupled degrees of freedom (as is the case of physical systems) or with significant uncertainty in inputs (as can be the case of option valuation, especially of real options, presented in chapter 4.2.).

Monte Carlo simulation attempts to follow the ‘time dependence’ of a model for which change does not proceed in some rigorously predefined fashion (like the movement of a particle according to Newton’s equations of motion) but rather in a stochastic manner which depends on a sequence of random numbers which is generated during the simulation (Landau, Binder, 2005). Its output is not a single-value but a probability distribution of all expected return, which, if the model represents a project evaluation, provides a complete risk/return profile of the project for the investor, showing all the possible outcomes that could result from the decision of investing on it.

Being heavily dependent on the capacity of generation of a large number of random numbers, this type of simulations only became mainstream in the last decades of the 20th century, with the proliferation of computers capable of undertaking this task (Kalos, Whitlock, 1986).

Monte Carlo simulation is an extremely valuable tool to value both financial and real options. Due to the complex nature of both BS and binomial models, the simulation technique provides an alternative mean to reach option values (Miller, Park, 2002).

The use of formulas that create random numbers in spreadsheet software is a way of implementing Monte Carlo simulations.¹⁷ The appearance of commercial software especially designed to this purpose¹⁸ became an easy way of running those simulations for those who do not master statistical calculations in regular spreadsheets, and presented a significant improvement, since before the arrival of such programs a new model had to be designed for each project being appraised.

A possible way of conducting such an analysis is presented in Figure 4.2.:

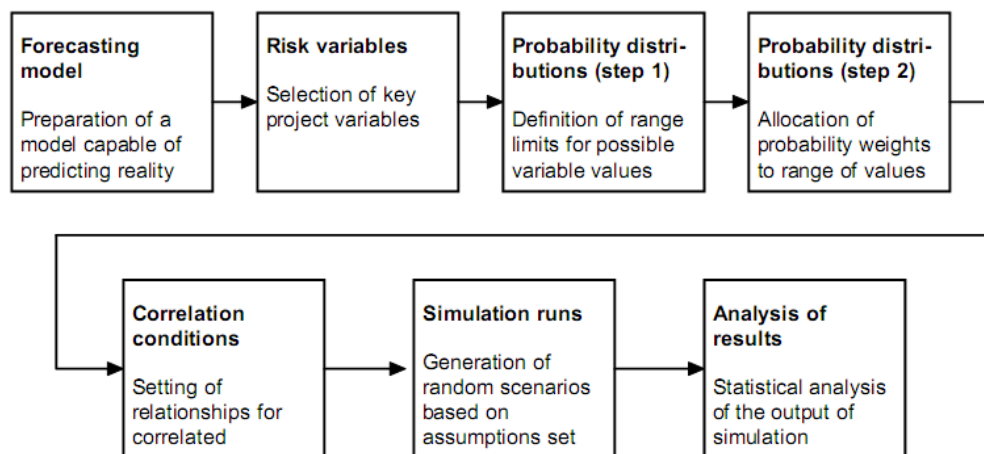


Fig. 4.2. – Monte Carlo simulation process.

Source: Savvides (1994)

¹⁶ Kalos and Whitlock (1986) report uses of Monte Carlo-like simulations since the 18th century (by Comte de Buffon and Laplace), but without modern digital computers these problems were too mind-blowing.

¹⁷ Like the RAND() function in Microsoft® Office Excel® 2007, which generates a number in the [0;1] range.

¹⁸ Oracle® Crystal Ball or Palisade® @Risk are two examples of this type of software.

The selection of key project variables is a key component of this process for a number of reasons (Savvides, 1994):

- If there are a lot of input variables, each one with its probability distribution, the possibilities of generating inconsistent scenarios is higher, since the determination of correlations between all the variables increases significantly.
- To correctly assess the probability distribution of each one of the variables takes a lot of time, and since many of those variables only have a small impact on the final result, the benefits of using them in the simulation are largely outweighed by the costs (in time and also in money).

Sensitivity analysis can also be used to estimate how variables influence the final outcome of a project, but since they only change one variable at a time their results can lead to unrealistic scenarios, because the variable may be correlated¹⁹ with other input variables. The exact assessment of the value of these correlations is not needed, since the purpose of using correlations is to restrain the model from generating grossly inconsistent scenarios in large scale, rather than achieving high statistical accuracy.

4.2. REAL OPTIONS

With the rapid expansion of option-pricing theory application on financial assets, it did not take much time for someone to realize that this concept could be applied to real assets and non-financial investments. First coined by Myers in 1977, the term *real options* (RO) appeared to reflect their association with real assets rather than financial assets.

But semantic caution is needed: in the context of real options, *option* has a specific, technical meaning. It is not a synonym for “alternative” as it is in ordinary language. An option refers to a choice, but a choice that the system designers and managers have deliberately made possible through some effort. It refers to flexibility and to the ability to adjust a design of a system in significant ways that enable the system managers to redirect the enterprise in a way that either avoids downside consequences or exploits upside opportunities (Neufville, 2004).

The use of options, although not explicitly, has been used by corporate executives for a long time. Every time a project is postponed or a contingency plan is prepared the management is exercising an option. Real options recognize and value this kind of flexibility and the staged nature of many investments. Projects that turn out to have negative NPV on a full-scale basis, may actually create value if undertaken in stages, and projects that may look attractive on a full-scale basis may look more attractive if undertaken in stages after resolving uncertainty (Herath, Park, 2002). RO tend to be most valuable in situations of high uncertainty and where the project without flexibility is near breakeven (Copeland, Keenan, 1998).

Valuing a project using real options theory (ROT) will not be needed when a project is either incredibly valuable or a complete disgrace. In those cases a simple DCF approach (combined with managerial capabilities) will tell the managers that the first one should be undertaken and the second one abandoned. But when uncertainty is large enough to make flexible solutions possible and waiting for more information a sensible decision, and when the value seems to be captured in possible project updates and mid-course strategy corrections, then real options provide a valuable framework to study those projects (Amram, Kulatilaka, 1999).

¹⁹ Two or more variables are said to be correlated if they tend to vary together in a systematic manner.

If there are no possible flexible solutions in a project, computing the NPV by standard models and by option valuation will give the exact same value. They diverge when there is a possibility of making choices within a project: for example, if there is a possibility of deferring a project. Choosing to defer a project may be good for a number of reasons, namely, the assumption that is always good to pay later rather than sooner (while waiting the time value of money can be earned on the deferred expenditure). Another reason for waiting is the constant changing nature of the world: the value of the assets may change during the waiting period, an apparent good businesses can turn into a bad one if prices goes down and vice-versa. By waiting, the ability to participate in good outcomes is still intact, while remaining sheltered of possible bad ones (Luehrman, 1998).

According to Miller and Park (2002), using real options bring two advantages when compared to DCF models. First, greater volatility does not translate into greater losses, because losses are limited to the initial investment. Second, the real options' value increases with a longer decision horizon, contrary to the DCF approach, where a lengthy time horizon just increases the project uncertainty, which lowers the project's value.

Overall, the point of using real options analysis is to estimate the value of flexibility in present value terms. Since that flexibility will only be put into effect if it provides to be more valuable than the inflexible scenario, the value of the option will always be positive (4.7) (Cardin *et al.*, undated). This is a significant piece of information for systems designers: by comparing the value of flexibility with the cost of acquiring it, they can make an informed, analytic judgment about whether this flexibility should be incorporated into design (Neufville, 2002).

$$V_{flexibility} = \text{Max}[0, NPV_{flexible} - NPV_{inflexible}] \quad (4.7)$$

Although ROT does not produce exact values, it produces estimates that might just be enough to make a decision: deciding does not require precise values, but just the relative value between exercising, or not, an option (Neufville, 2003).

Regardless all those advantages and a history of more than thirty years, RO still did not became as mainstream as NPV based techniques. A study conducted by Block (2007) with a sample from *Fortune* 1000 largest companies, showed that 14,3 percent of the respondents use real options in their capital budgeting process.²⁰

Amram and Kulatilaka (1999) consider that this slow adoption of RO in the corporate world is due to the focus on the technical aspects of the theory, which can be mind-boggling, rather than in, what they call, the RO's way of thinking:

- *Options are contingent decisions.* An option is the opportunity to make a decision after uncertain factors are clarified. Contrary to the linear payoff of a fixed decision, the payoff to an option is non linear, because it changes with the decision made.
- *Options valuations are aligned with financial markets valuations.* RO uses the same tools and concepts has financial options to value complex payoffs across all types of real assets.

²⁰ From the 1000 companies listed in Fortune, 279 usable responses were returned to the author. From those 279, 40 companies assumed the use of real options, being only 1 of them in the transportation industry (from 12 in the original 279 companies sample). The author also reports other studies, conducted in 2002 and 2003, where 11,4 percent and 9 percent of the companies, respectively, used real options.

- Options thinking can be used to design and manage strategic investments proactively. By identifying and valuing the options in a strategic investment, the investment can be redesigned and proactively managed to better use those options.

4.2.1. TYPES OF REAL OPTIONS

4.2.1.1. Real options on projects

Several types of real options can be found within a project. Table 4.2. sums up a classification often used.

Table 4.2. – Different types of real options.
Source: Adapted from Ohama (2008) and Brealey and Myers (2000)

Type	Description	Implementing Criteria
Options to wait	It is equivalent to owning a call option on the investment project. Investing now might be profitable, but it might be also profitable tomorrow. Deferral is most attractive when uncertainty is great and immediate project cash flows – which are lost or postponed by waiting – are small.	Max [immediate investment, waiting, 0]
Options to expand	Expanding the level of projects allows greater participation in upside. Today's investments can generate tomorrow's opportunities. Cost of expansion is analogous to strike price.	Max [current status, expanded project]
Options to restart temporarily closed operation	Similar to options to wait to invest or expand.	Max [remain closed, re-open operation]
Options to abandon	Abandoning investment can eliminate further losses in projects, which includes shut down costs and salvage prices, providing partial insurance against failure. It is similar to a put option, being the put's exercise price the value of the project's assets if sold or shifted to a more valuable use.	Max [continuing, abandoning]
Options to contract	Options to contract can reduce the participation level and exposure to losses, although it basically incurs in short-term scale down costs.	Max [current status, contracted project]
Options to shut down operations temporarily	This is a special case of options to contract, and it can eliminate losses, but incur in shut-down costs.	Max [current status, temporarily shut down]
Combinations of options	Combinations of options above.	-

The options presented in Table 4.2., which closely mirror financial options in terms of use, applying various options pricing models to evaluate the value of managerial flexibility, are normally referred as real options *on* projects. This kind of options treat technology as a black box and are applied when uncertainty comes from the market factors that firms cannot control such as future demand (Wang, Neufville, 2006 and Ohama, 2008). Most of real options literature focuses on this type of options.

Table 4.3. presents the differences between an American call option and a real option on a project:

Table 4.3. – Comparison between an American call option and a real option on a project.

Source: Adapted from Li and Johnson (2002) and Carvalho (2005)

American Option on Stock	Real Option on a Project	Variable
Current stock price	Present value of expected cash Flows	S
Option exercise price	Investment cost	K
Time to expiration	Time window of the investment opportunity	t
Riskless interest rate	Discount rate	r
Stock price uncertainty	Project value uncertainties	σ^2
Right to exercise the option earlier	Right to invest in the project before the opportunity disappears	-
Traded in a financial market	Usually not traded	-
Easy to find a replicating portfolio	Hard to find a replicating portfolio	-
Only the holder has rights over them	The holder and his competitors might share the rights to exercise the option	-

4.2.1.2. Real options *in* projects

Alternatively, when the flexibility lies within the design of the system or projects, these options can be called real option *in* projects, and are created by changing the actual design of the technical system.

Real options *on* projects are mostly concerned with the valuation of investment opportunities, while real options *in* projects are mostly concerned with design of flexibility. Real options *on* projects do not require knowledge on technological issues, and interdependency/path-dependency is not frequently an issue. However, real options *in* projects need careful consideration of technological issues. Complex technological constraints often lead to complex interdependency/path-dependency among projects (Wang, Neufville, 2005).

Table 4.4. presents a comparison between real options *in* and *on* projects.

Table 4.4. – Comparison between real options *in* and *on* projects.

Source: Wang and Neufville (2005).

Real Options <i>on</i> Projects	Real Options <i>in</i> Projects
Values opportunities	Design flexibility
Valuation important	Decision important (go-or-no-go)
Relatively easy to define	Difficult to define
Interdependency/path-dependency not an issue	Interdependency/path-dependency an important issue

Wang and Neufville (2005) explain the specific difficulties real options *in* projects face:

- To define this kind of real options one must have competence not only in the financial aspects of the project but also in the technology involved;
- Real options *in* projects are complex and interdependent: the usefulness to value every element that provides flexibility is not clear;
- They tend to be path-dependent, i.e., their value depends on previous states of the system and they also are dependent from other options in the project, thus becoming compound options.

4.2.2. VALUING REAL OPTIONS

Although being equivalent in some ways to financial options, real options have some fundamental differences that must be addressed in order to properly evaluate them. Hodota (2006) identifies two points in which this distinction is clearer:

- In a financial option, the *underlying asset* is just it, the underlying asset, for example the stock price in a stock option. In RO, the underlying asset is the agent that influences the value of the project, for example, the gold price in a gold mine valuation.
- The time span of RO is normally considerably longer (it can last a few decades) than their financial counterpart (with a normal maximum time span of two years).

Those differences add a degree of complexity to RO, but that does not mean that standard option valuation tools, discussed in chapter 4.1.1. cannot be used when valuing these options.

Every one of the models presented has some advantages and some drawbacks.

For example, BS model can give a result very easily, but the determination of each variable can be difficult and it is applicable to only one decision date.

Binomial lattices can value American options and gives managers an approximate evolution of the value of the underlying asset, but it is difficult to set several uncertain factors at the same time.

Finally, simulations are the easiest tool for anyone not familiar with very advanced financial tools and its results can be presented visually, but its results do not demonstrate the true value of projects.

The advantages and disadvantages of each one of the presented methodologies must be taken into account when valuing a project by the use of ROT, so that the model chosen is appropriate for the characteristics of the project in question.

Table 4.5. provides a summary of the pros and cons of each methodology.

Table 4.5. – Advantages and drawbacks of each model when evaluating real options.

Source: Adapted from Ohama (2008)

Model	Advantages	Drawbacks	Targeted Audience
Black-Scholes	Provide rough estimation. Easy to calculate the value.	Applicable to only one decision date. Difficult to model what would happen in the real situation. Underlying assumptions and their estimation limit its use (price, volatility, duration, etc.).	Project managers and designers with advanced financial knowledge.
Binomial lattices	Provide approximate evolution of the value of the underlying assets in a simple but flexible way. Illustrate the intermediate decision-making processes between now and the exercise of the option, which guides decision-makers to understand how they should decide at each point in time. Provide the true value of projects based on financial theory.	It is necessary to understand real options approach in terms of financial theory. Difficult to set several uncertain factors in the analysis at the same time.	Managers and decision-makers with advanced financial knowledge.
Simulations	Not necessary to understand financial theory. User-friendly tools are available. Demonstrate the analysis result visually. Model several uncertain factors at the same time.	Does not produce the true value of projects.	Any managers and decision-makers without advanced financial knowledge.

Regardless of the model used, Copeland and Antikarov (2003) proposed a four-step valuation process for real options (Figure 4.3.), that starts with a standard, inflexible, valuation, and then expands to include the flexible solutions.

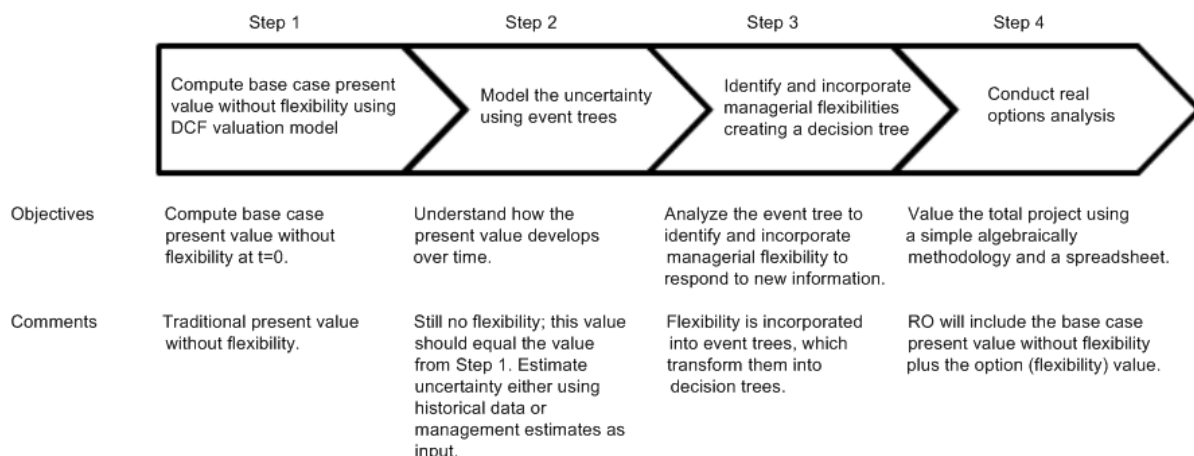


Fig. 4.3. – Four-step valuation process for real options.

Source: Adapted from Copeland and Antikarov (2003)

4.2.3. SOME USES OF REAL OPTIONS

4.2.3.1. Options to defer/expand

Computing a NPV for a project only provides the value of the project at one point in time. Waiting for more information and holding the investment off can prove to be valuable and even if a project has a negative NPV, having the right (*but not the obligation*) to undertake the project in a moment in the future has value.

Even if the project NPV is positive, a company can still wait and invest only when the project becomes more profitable. This is especially true in projects with high levels of volatility.

Figure 4.4. presents a diagram for the option to delay, and is comparable with the diagram of a call option. In this case, the underlying asset is the project itself, the strike price of the option is the investment needed to take the project, and the life of the option is the period for which the firm has rights to the project. The present value of the cash flows on this project and the expected variance in this present value represent the value and variance of the underlying asset.

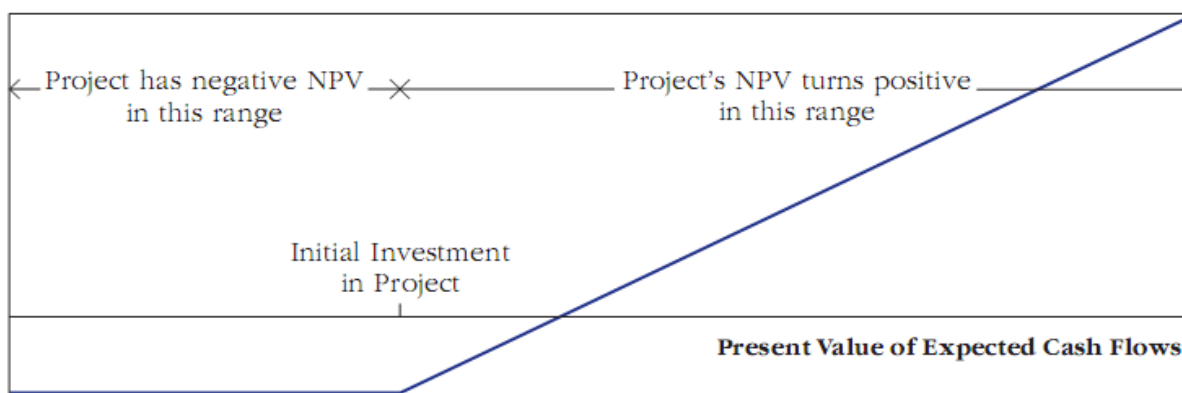


Fig. 4.4. – The option to delay or expand a project.

Source: Damodaran (2000)

This call option-like diagram can also be used to exemplify the option to expand a project, with the sole difference of the initial investment in the project being replaced by the cost of expansion. The option to expand arises when a company does not want to commit large amounts of money in a project without more information on its profitability, but by making a small investment in the beginning opens new investment opportunities that may be, or not, seized when more data is available. This option can be used when a project has a negative NPV, but, by investing on it, the company opens significant opportunities that otherwise would be closed (Damodaran, 2000).

4.2.3.2. Options to abandon

When the project does not go according to plan, the managers have always the possibility to close operations and try to salvage whatever is left. If cash flows fall below a certain threshold closing might be for the best benefit of the shareholders before all value is lost (Figure 4.5.)

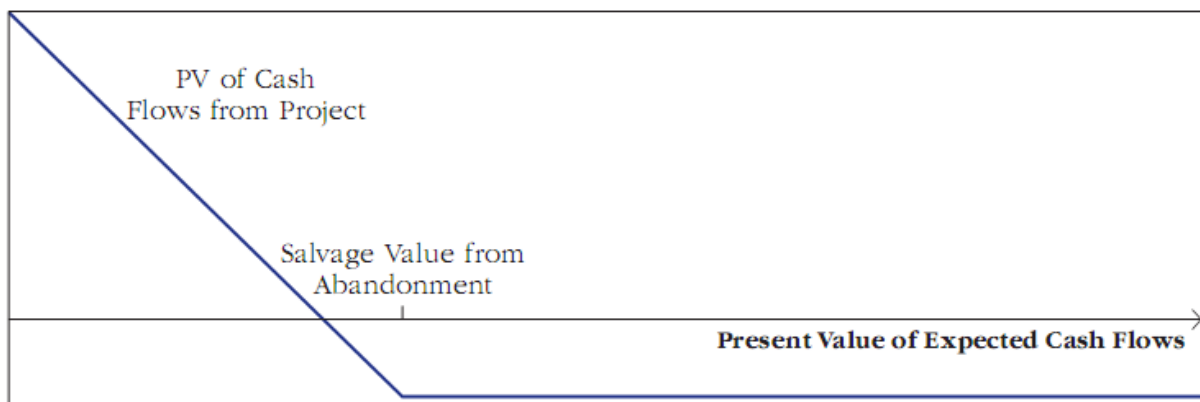


Fig. 4.5. – The option to abandon a project.

Source: Damodaran (2000)

4.2.3.3. Examples

A paradigmatic example of the use of options in a complex engineering system was done even before the appearance of the concept of real options: the April 25th Bridge over the river Tagus in Lisbon (Neufville, 2003). This bridge, originally intended to serve only road traffic in its upper deck, was built with a lower deck capable of receiving rail tracks in the future. This created an option and the right to install a rail service if desired by national and local authorities. In fact, more than two decades later after the opening of the bridge, the government decided to strengthen the structure, widen the upper deck, install rail tracks in the lower one and a suburban rail service eventually opened and is now continuously connecting the two banks of the river. Nowadays, the bridge is also used by long haul trains.

One significant use of real options is the valuation of natural resources. For example oil and gas (Lin, 2008; Copeland, Antikarov, 2005; He, 2007) or mining (Damodaran, 2001; Cardin *et al.*, 2008). Opening a new oil extraction field or re-opening a gold mine are good examples of contingency options that can be evaluated by real options: it only payoffs to make the investment to make the extraction if the resource's price is above a certain threshold, and acquiring the rights to do so is similar to the strike price of a call option, and if the price falls below another certain threshold it might pay off to temporary shut down operations or even abandon the project completely. Real options can help managers compare the various possibilities they have and make the most out of uncertainty.

Academic research, resulting in a significant number of papers and thesis, has been produced at the Massachusetts Institute of Technology (MIT), mostly by or under the supervision of Professor Richard de Neufville.²¹ This research include such different projects as: a multi-level car parking (Neufville *et al.*, 2005); airport design (Chambers, 2005; Ohama, 2008); Intelligent Transportation Systems (McConnell, 2007); hydropower projects (Mittal, 2004; Wang, 2003); hospital expansions (Maseda, 2008); water supply systems (Ramírez, 2002); etc.

Miller and Park (2002), compiled more than 40 examples of real options applications, from such industries as biotechnology, manufacturing, natural resource exploration, research & development or technology, although most of them are mere academic exercises rather than applications in the economy.

Triantis (2005) keeps a database of literature on real options²² and estimates that there are more than 1000 papers on the subject, so one can argue that real options is a topic being studied by a significant number of people in the academic environment and the transposition from the academia to the real economy should be already in motion, at least in some industries.

4.2.4. CRITICISM OF REAL OPTIONS

Like all theories, ROT use is not immune to critics. Triantis (2005) aggregated criticism of real options into four main categories:

- Real options have been accused of being one of the causes of the burst of the Internet bubble back in 2000, which the author thinks is ludicrous, since only one Internet company (Amazon.com) is known to have been analysed using real options and the authors of the evaluation estimated a value for the company reasonable close to the post-crash stock value;
- Decision analysts tend to question the originality and appropriateness of real options analysis, since decision analysis already incorporates uncertainty in its valuation processes;²³
- Real options models reflect “perfection” rather than economic reality, assuming that managers are completely rational, loyal to the shareholders’ interests and capable of making the right decisions at exactly the right time;
- The final critic real options face, regards the complex implementations of its models, with the difficulties associated of choosing the right model to use and then estimate correctly the variables it needs (volatility, discount rate, underlying asset, etc.).’

Fink (2001) argues that real options only work if a company is truly prepared to cancel a project if it turns unprofitable, and the true flaw in ROT is not its modeling complexity, but rather the fact that it ignores the psychological and political realities of capital investments: many companies continue to fund projects even when they aren't living up to expectations, sometimes just because the managers involved have a vested interest in seeing them continue. The author then argues an option's value often has more to do with a company's management and organization than with the methodology's application.

²¹ Professor of Engineering Systems and of Civil and Environmental Engineering

²² <http://www.rhsmith.umd.edu/faculty/atriantis/RealOptions1.html>

²³ Decision analysis is a model of valuation that includes uncertainty, and where the main possibilities of a system are evolved over time, discounted to a NPV, and then probability weighted back to the present to identify the best strategy (Quispez-Asin, 2006).

5

THE MODEL

5.1. MODEL EXPLANATION

In order to evaluate the benefits of considering flexibility when designing and managing an airport, a model, using Microsoft® Office Excel® 2007, was developed.²⁴

This model contained two different scenarios, each one with two different settings.

In the first, inflexible and deterministic, scenario the airport is considered to be constructed all at once, for a maximum annual capacity of 50 million passengers (MPax). The second scenario has flexibility embedded in it: the traffic forecasting is based on probabilities and the airport is built in different stages only when additionally capacity is needed (a few years before, actually).

Although in a real world situation building an airport of this size would be subjected to a lot of restrictions and constraints, like available land, environmental issues, etc., in the model it is assumed that there are no restrictions (besides the necessary capital expenditures) to build the airport with the desired capacity.

This modelling approach, which considers the airport as a whole, is different from other studies regarding this subject, like the Master thesis developed by Chambers (2005) in the Massachusetts Institute of Technology, in which two different models, one for the airside and one for the landside, were developed and applied to a case study in Portugal (the now abandoned *Ota* Airport project).

5.1.1. TYPES OF AIRPORTS CONSIDERED

In both scenarios, two different types of airports were considered: *low-cost airports* (LCA), primarily intended to serve LCC and *full service airports* (FSA), which are mainly used by regular, non low-cost, carriers. The distinction between the types of airports is used to accommodate the differences in cash flows patterns each type of airline generate to an airport.

The *inflexible* airports were opened at year 0 with full capacity (50 MPax), which meant they would remain with overcapacity for a number of years from its opening. In this case it is assumed that the capital expenditures necessary to open the airport are all done in year 0, and there are no more expenses with facilities, besides the normal maintenance costs (include in the outflows generated by passenger activity).

²⁴ After the conclusion of this thesis, the model will be available publicly.

In the flexible scenarios, a small airport (15 MPax for a FSA and 5 MPax for a LCA) is opened in year 0. Afterwards, when passenger activity reaches a percentage of the maximum installed capacity (90 percent, for a full service airport, and 95 percent for a low-cost airport²⁵) the airport is upgraded in 5 MPax increments.

Since expanding an airport takes time, the construction of these *upgrades* will start 2 or 3 years (for a low-cost and for a full-service airport, respectively) before the mentioned threshold in order to allow the opening of the new facilities when passenger activity exceeds the installed capacity. The capital expenditures needed for the construction of those expansions are included in the when year construction begins.²⁶

5.1.2. VALUATION PROCEDURE

5.1.2.1. Inflexible Scenarios

In order to evaluate the different scenarios, it was necessary to forecast traffic for the future.

For the case of the deterministic settings, the demand was established to be 2 MPax at year 0. Then, an annual geometric growth rate²⁷ was applied to that initial demand to a total of 51 periods, from year 0 to year 50. If at some point in the future the maximum capacity of 50 MPax was exceeded, it was assumed that the airport continued to serve only 50 MPax, even if the demand was higher.

Both the construction of the airport at year 0 and the passenger activity generated cash flows that were determined on an annual basis and then used to assess the NPV of the project.

The present value was estimated using both FCF and CCF models, already presented in Chapter 3. Estimations for the discount rates used in the model are presented in Chapter 5.5.

The FCF model is applied in a straightforward way: cash flows are discounted with the WACC discount rate, and then the sum of all present value cash flows plus the initial CAPEX constitutes the NPV.

CCF model has some differences that must be underlined: since this model takes into account debt tax shields before applying the discount rate (K_A), the estimation of the present value of the cash flows is done after subtracting corporate taxes (only when there are positive cash flows, i.e., profits) and possible debt tax shields.

Using the Portuguese fiscal landscape, where losses in one year can be divided into six different years, the model assumes that corporate taxes would only be applied at the seventh period (or year 6), since at year 0 the construction of the airport generated major capital expenditure, that could be divided into the subsequent years.

From year 6 to year 51 a corporate tax of 27,5 percent²⁸ was applied to the cash flows and then all fifty one cash flows, including CAPEX resulting from the initial construction and posterior expansions, were discounted using the expected asset return (K_A) and summed, which resulted in a NPV for the CCF model.

²⁵ This distinction is due to the fact that it is considered that FSA should offer greater levels of quality service than LCA, then they should begin expansion earlier to ensure the maintenance of those quality levels during construction.

²⁶ It was considered that the construction of new facilities in a low-cost airport should be done more rapidly, since they are normally simpler than the equivalent ones in a full service airport, and therefore the expansion is only needed when the airport is closer to reach the capacity limit than in a full service airport.

²⁷ Its estimation is presented in Chapter 5.3.

²⁸ Explanation of this value is presented in Chapter 5.5.

5.1.2.2. Flexible Scenarios

The process to evaluate the flexible settings was not so straightforward. First, a binomial lattice (for each type of airport) containing expected passenger movements was built and the probabilities for each node were calculated²⁹. Afterwards, if there was a need for expansion in a certain node (following the assumptions already mentioned), the investment was anticipated to 2 or 3 years before, depending on the type of airport.

With the information regarding the necessary expansions, it was then possible to estimate cash flows for each one of the 1326 nodes of the lattices and their corresponding probabilities. The expected cash flow of each period was then calculated as the sum of the probability weighted cash flows of the nodes in that period.

Applying the discount factors of both FCF and CCF models, and then applying the corporate tax to the latter, it was possible to estimate the expected NPV values for 10, 20, 30, 40 and 51 years, and the corresponding option value, which is simply the difference between the inflexible scenarios NPVs and the ones calculated in the flexible scenarios (5.1).

$$\text{Option value} = NPV_{\text{inflexible scenario}} - NPV_{\text{flexible scenario}} \quad (5.1)$$

Another option in this scenario was also studied: if the traffic fell below 1 MPax, the airport would be closed and 30 percent of the initial investment was salvaged by selling the remaining facilities.

NPVs and option value by both FCF and CCF models were again estimated and comparison between flexible NPVs was also calculated: the *abandonment option value* (5.2), which is the difference between the flexible NPV with the abandonment option and the flexible NPV without that option.

$$\text{Abandonment option value} = NPV_{\text{abandonment option}} - NPV_{\text{flexible scenario}} \quad (5.2)$$

The final result of the model are eight different settings, four for each scenario (flexible and inflexible), and within each scenario two types of airports valued by two different models (Figure 5.1.).

²⁹ The inputs used in the construction of these lattices are presented in chapter 5.6.

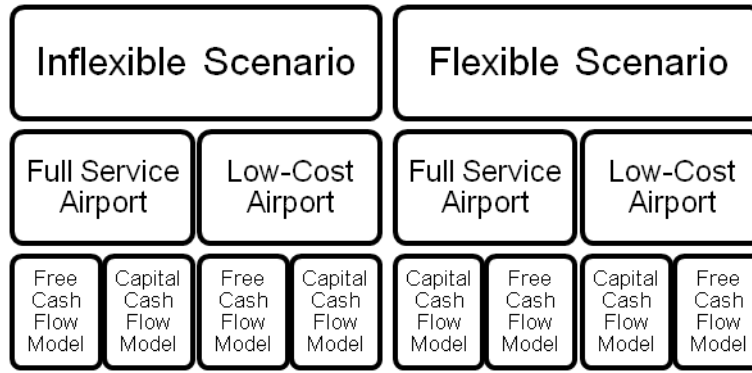


Figure 5.1. – Final results produced by the model.

5.1.2.3. Sensitivity Analysis and Monte Carlo Simulation

After the whole range of NPVs were estimated in the various scenarios, in order to estimate how changing the input variables affect the final results, a sensitivity analysis was conducted in order to estimate the most influent variables in the final results.

This analysis was conducted by changing all variables individually by ± 15 percent (a total variation of 35,29 percent – equation 5.3), and then assessing how the NPVs variation for all the settings considered (flexible and inflexible scenarios, for both valuation models and for the two types of airports, resulting in a total of eight NPVs).

$$\text{Total variable variation} = \frac{\text{Variable} + 15\%}{\text{Variable} - 15\%} - 1 (\%) = 35,29 \% \quad (5.3)$$

Varying the variables by the mentioned ± 15 percent resulted in a variation of the NPVs, presented also in percentage (5.4). Then, that percentage was compared to the initial variation of 35,29 percent produced in the changing variable, and a sensitivity absolute value was produced (5.5)

$$\text{NPV variation} = \frac{NPV_{\text{Variable} + 15\%} - NPV_{\text{Variable} - 15\%}}{NPV_{\text{without variation}}} \quad (5.4)$$

$$\text{Sensitivity} = \left| \frac{\text{NPV variation} (\%)}{\text{Total variable variation} (\%)} \right| = \left| \frac{\text{NPV variation} (\%)}{35,29 \%} \right| \quad (5.5)$$

The three variables with higher sensitivity values were then chosen, correlations between them were established and then a number of Monte Carlo simulations (50.000 for each setting) were run in order to estimate the probabilities of achieving positive NPVs after the longest period considered in the analysis, i.e., 51 years.

5.2. FLEXIBLE SUBSYSTEMS CONSIDERED

Table 5.1. presents the costs considered in the model for the construction of the two types of airports, with all subsystems being aggregated into one value per 5 MPax increments:

Table 5.1. – Investments on the two types of airports considered.

Source: Adapted from Centro de Estudos de Gestão e Economia Aplicada - Faculdade de Economia e Gestão da Universidade Católica Portuguesa and TRENMO (2007)

Capacity (MPax)	Total Investment Needed (€)	
	Full Service Airport	Low-Cost Airport
5	-	292.110.000
10	-	365.619.000
15	846.370.000	446.618.000
20	976.910.000	538.638.000
25	1.135.591.000	643.819.000
30	1.477.991.000	863.169.000
35	1.596.440.000	936.678.000
40	1.737.359.000	1.017.677.000
45	1.899.999.000	1.109.697.000
50	2.074.730.000	1.214.878.000

These costs were adapted from the report *Avaliação Económica do Mérito Relativo da Opção “Portela + 1” - Estudo de impacte da localização de um novo aeroporto na região de Lisboa* (hereafter referred as CEGEA and TRENMO, 2007), which only had estimations until 30 MPax, so extrapolations until 50 MPax were conducted and all values were rounded to million euros.

Costs presented in Table 5.1. include, between others:

- The construction of two runways, each one with a capacity of 25 MPax (therefore, the second runway is constructed after the 25 MPax capacity is exceed);
- Taxiways, parking positions for planes and other facilities regarding the *airside* of the airports, like maintenance hangars;
- Terminals, with luggage processing facilities, offices, VIP area, air conditioning, etc.;
- Technical equipments, like the control tower, police station and firemen headquarters;
- Support systems, as parking places for passengers and airport employees, fuel storage facilities and road accesses inside the airport premises
- Environmental systems, consisting of air, water and noise monitoring systems;

To account possible unexpected costs, a 7 percent multiplier was applied to all subsystems' costs.

This model makes two important assumptions:

- Costs have the same value regardless of the moment when expansion takes place, i.e., expanding the airport in the future costs as much as expanding it in the present.
- Costs do not include site-specific parameters, like preparation of the site (ground leveling, for example).

The complete costs for all subsystems considered are presented in the appendices (Tables A.3. and A.4.).

5.3. TRAFFIC FORECAST

A major component in a real options valuation, with vast implications in the performance of the binomial lattices and consequently in the final results, is the accurate estimation of the growth rate (v) and the corresponding volatility (σ^2) of the parameter being analyzed – in this case, the passenger traffic patterns in an airport.

To estimate those two variables, sample data regarding European airports from 1993 to 2007 was collected from Eurostat.

In order to have more relevant results, it was decided to ignore the airports with one or more years of data missing, and also the ones that had less than 100.000 passengers in the first year of data available (1993). Those constraints meant that only 30 airports (with 11,11 percent of annual growth and a volatility of 16,55 percent), mainly from Austria and Germany, would be taken into account.

A new period, ranging from 2002 to 2007³⁰, was then chosen in an attempt to have a more significant data sample. The constraints applied were the same as before, and resulted in a total of 221 airports from 20 countries (including six from Portugal). The average annual growth of this sample was 8,11 percent with a volatility of 4,38 percent.

Since the model individually evaluates the construction of an airport targeted for LCC it was necessary to estimate separately average growth rates and volatilities for this kind of airports.

The choice of which airports represent *low-cost airports* was based on CEGEA and TRENMO (2007) and on a paper by Neufville (2007). These sources cited 10 airports from 5 countries (from the original 221 airports from 20 countries) that could be considered low-cost airports. Those airports had an average annual geometric growth rate, in the same 2002-2007 period, of 22,83 percent with a volatility of 7,11 percent.

5.4. INFLOWS AND OUTFLOWS

To determine cash flows patterns generated at an airport, CEGEA and TRENMO (2007) used data collected from ANA³¹ and Instituto Nacional de Estatística³² about Lisbon airport (which represents the FSA) and Faro airport (which was considered as a LCA) from 2001-2005 to estimate the inflows resulting from passenger movements.

Those inflows included not only revenues directly attributed to passenger movements, but also other revenues like aircraft taxes. All those inflows were then aggregated into one inflow per passenger (the

³⁰ This period was specifically chosen in order to represent the evolution of air traffic after 9/11.

³¹ ANA *Aeropostos de Portugal*, S.A. is the government-owned company that owns all Portuguese airports in the mainland and in the Azores.

³² The National Statistical Institute of Portugal.

quotient between total revenues and the total number of passengers – equation 5.6), that aims to represent the total revenue one passenger generate when in the airport, even if not directly originated by the passenger.

$$\text{Inflow per passenger} = \frac{\sum \text{Inflows generated at the airport}}{\text{Total number of passengers}} \quad (5.6)$$

Since ANA does not reveal detailed information about its expenses, CEGEA and TRENMO (2007) used a large database of European airports in order to estimate outflows per passenger (like in the case of inflows, outflows *per passenger* include all expenses, not only those directly related to passenger movements). This calculation resulted in ratios between operating expenses and revenues for the two types of airports considered in the thesis:

- 65 percent for full service airports;
- 75 percent for low-cost airports;

So, the net profit ratio³³ is 25 and 35 percent for LCAs and FSAs, respectively.

The inflows and outflows considered in the model are presented in Table 5.2.

Table 5.2. – Passenger related cash flows.

Source: CEGEA and TRENMO (2007)

		Revenues (€\Pax)	Expenses\ Revenues	Expenses (€\Pax)	Profit (€\Pax)
Type of Airport	Full Service	11,07 €	65%	7,20 €	3,87 €
	Low-Cost	9,56 €	75%	7,17 €	2,39 €

The assumption, implied in this model, that there are no economies of scale with the increase of the number of passengers, makes the number of passengers the only risky variable in the project (CEGEA and TRENMO, 2007).

5.5. MODEL SPECIFICATION AND PARAMETERIZATION

To estimate the value of the Weighted Average Cost of Capital (3.2), the cost of equity (3.3), and the expected asset return (3.5) some variables need to be estimated.

The risk-free rate (r_F) was estimated with the 30-year Portuguese Treasury bond³⁴ as a proxy, and its value in May 13, 2009, was 4,642 percent. The cost of debt (K_D) used was the risk-free rate plus a spread of 2,0 percent (defined by the author).

³³ Net profit ratio (or profit margin) is a measure of profitability and is estimated as the ratio between net profit and total revenues.

³⁴ Since the project maturity is 51 years, a bond with a maturity close to that value should have been chosen, but Portugal does not issue treasury bonds with a maturity longer than 30 years.

The corporate tax was based on the Portuguese income tax rates, and its value is 27,5 percent, being 25 percent the national income tax rate plus a local tax rate surcharge of 2,5 percent (10 percent of the 25 percent national income tax rate).

The level of financial leverage considered in the model was based on the work of Kleimeier and Megginson (2001), which studied 4956 project finance loan operations (worth \$634,4 thousand millions) and concluded that they had an average level of financial leverage (“average loan to project value ratio” in the quoted paper) of 67 percent.

The market risk premium was based on the database maintained by Professor Aswath Damadoran from New York University’s Stern School of Business.³⁵ Last update in January 2009, the value for Portugal was 6,50 percent.

Estimating the asset beta value for an infrastructure such as an airport is not an easy task. Alexander *et al.* (1999) proposed a value of 0,5877 for airports located in Europe, which means investing in an airport is less risky than investing in a complete market portfolio.

5.6. BINOMIAL LATTICES INPUTS

Using the data estimated in Chapter 5.3 regarding traffic forecasting, and equations 4.6., 4.7. and 4.8. presented in Chapter 4.1.1.2. it is possible to estimated the necessary input data for constructing the proposed binomial lattices (Table 5.3.).

The time factor (Δt) considered was one year.

Table 5.3. – Data inputs for the binomial lattices. Calculations by the author.

	Type of airport	
	Full Service	Low-cost
Annual Growth Rate (ν)	8,11%	22,83%
Volatility (σ^2)	4,38%	7,11%
Time factor (Δt)	1	1
Increase Factor (u)	1,23	1,31
Decrease Factor (d)	0,81	0,77
Probability Increase Factor (p)	0,69	0,93
Probability Decrease Factor ($1 - p$)	0,31	0,07

³⁵ <http://pages.stern.nyu.edu/~adamodar/> – select “updated data” and in “Data Sets” select “Risk Premium for other Markets” in the “Discount Rate Estimation”.

6

RESULTS

6.1. FINANCIAL PARAMETERS

Applying the model required the determination of a few financial parameters, which results depended on the variables presented on Chapter 5.5.

The results of the calculations made for the estimation of those variables are presented in Table 6.1.:

Table 6.1. – Estimation of financial variables.

Variable	Result
Equity Beta (β_E)	1,7809
Cost of Debt (K_D)	6,642%
Cost of Equity (K_E)	16,22%
Expected Asset Return (K_A)	8,46%
WACC	8,58%

6.2. INFLEXIBLE SCENARIO

Using all the constraints, assumptions, and input data introduced in Chapter 5 and the FCF and CCF models it was possible to estimate a number of NPVs for each one of the airports considered in the analysis.

Table 6.2. presents a summary of the results for the inflexible scenario. More complete results are shown in Tables A.5. and A.6. in the appendices.

Table 6.2. –Results for the inflexible scenario.

	Type of Airport			
	Full Service		Low-Cost	
Results	FCF	CCF	FCF	CCF
NPV - 10 years	-1.998.741.878 €	-2.006.693.231 €	-1.126.302.058 €	-1.139.273.342 €
NPV - 20 years	-1.926.000.584 €	-1.953.132.325 €	-875.646.437 €	-954.621.179 €
NPV - 30 years	-1.856.367.387 €	-1.901.307.961 €	-712.065.298 €	-832.959.075 €
NPV - 40 years	-1.789.709.484 €	-1.851.163.838 €	-640.235.543 €	-778.961.129 €
NPV - 51 years	-1.736.264.563 €	-1.810.535.672 €	-606.743.687 €	-753.502.770 €

The results obtained were highly unprofitable, especially in the FSA. Even at a time horizon of 51 years, where both airports operate at full capacity, the NPV does not become remotely close to the break-even point.

With the annual growth rates considered, the full service airport (with an annual growth rate of 8,11 percent, which mean passenger movements would double every 9 years), would have its capacity exceed in year 42, operating at full capacity for 9 years. In the low-cost airport, with its growth rate of 22,83 percent (passenger movements double every 4 years), capacity would be exceeded in year 16, operating at full capacity for 35 years, which translates into higher NPVs in the final decades analyzed (in the first 10 years the difference between FSAs and LCAs is a little bit below 1,0 thousand million euros in both valuation models, and expands to almost 1,5 thousand million in the final NPV considered at year 51).

Remarkably high construction costs combined with relatively low net profit ratio (25 percent for the LCA and 35 percent for the FSA) pave the way for the achieved results.

Chambers in his 2005 Master thesis produced at MIT, developed two models, one for an airport's terminal and other for a runway. As already mentioned in Chapter 5.1., these models were subsequently applied to a case study in Portugal, regarding the now-defunct *Ota* International Airport project. In the terminal model Chambers used a range of cash flows very different from the ones used in the present thesis, with net profit ratios of over 80 percent.³⁶

Although applied in a case study based in the Portuguese situation, these cash flows greatly differ from the ones estimated by CEGEA and TRENMO (2007), representing profits more than three times the ones estimated in the mentioned report. It was decided to use this data³⁷ merely as a mean of comparison, since if it can represent revenues for some airports, certainly they do not represent Portuguese ones, at least in current market conditions.

³⁶ This model considers the following revenues per passenger: \$20 (€14,29, being €1=\$1,4) for full service airports and \$16 (€11,43) for the low-cost airport. Expenses were considered to be equal to both type of airports and its value is \$3 (€2,14).

³⁷ Since Chambers' terminal model only includes the cost of construction for the terminal – unlike the current thesis, which considers the airport as a single system with different subsystems –, it was decided to only change the range of expected cash flows while maintaining the construction costs unchanged.

Using Chambers data resulted in very different results, as can be seen in Table 6.3.

Table 6.3. – Results for the inflexible scenario, with new data.

Results	Type of Airport			
	Full Service		Low-Cost	
	FCF	CCF	FCF	CCF
NPV - 10 years	-1.899.591.549 €	-1.917.917.935 €	-939.884.907 €	-980.155.589 €
NPV - 20 years	-1.731.936.430 €	-1.794.470.034 €	-161.698.837 €	-406.884.020 €
NPV - 30 years	-1.571.444.897 €	-1.675.024.539 €	346.155.576 €	-29.171.546 €
NPV - 40 years	-1.417.810.861 €	-1.559.451.686 €	569.158.415 €	138.470.611 €
NPV - 51 years	-1.294.630.284 €	-1.465.811.339 €	673.137.316 €	217.508.696 €

In this new scenario the airport proves to be a much more desirable investment, especially the low-cost one, which turns out profitable after 32 years even in the worst case scenario (using the CCF model), since the full service airport remains with a negative NPV even after 51 years (but even in this case, its NPVs are 500 million euros higher than before).

Comparing the results from the different sources of data used, it appears that in order to make the construction of an airport a more appealing project for the investors (at least in Portugal, where the base data comes from) the focus should be on maximizing the net profit ratio, while reducing construction costs.

6.3. FLEXIBLE SCENARIO³⁸

The use of binomial lattices enabled the forecasting of passenger activity in a more dynamic way, compared to the deterministic forecast explained earlier.

Using this model it was possible to estimate a range of possible passenger activity for each one of the 50 years forecasted (the level of passenger activity at year 0 was pre-determined by the author) along with the probabilities associated with each forecast.

These results for the final year considered (year 51) are represented in a x-y graphic, being the x-axis the total number of passengers, and the y-axis the probabilities of each results (Figures 6.1. and 6.2., for a FSA and a LCA, respectively).

³⁸ This scenario implied the construction of a significant number of binomial lattices which, if were to be all presented in this chapter, would make the text unreadable. So, only the main results will be presented in the chapter, and more complete data tables are presented in the appendices, starting from page A.10.

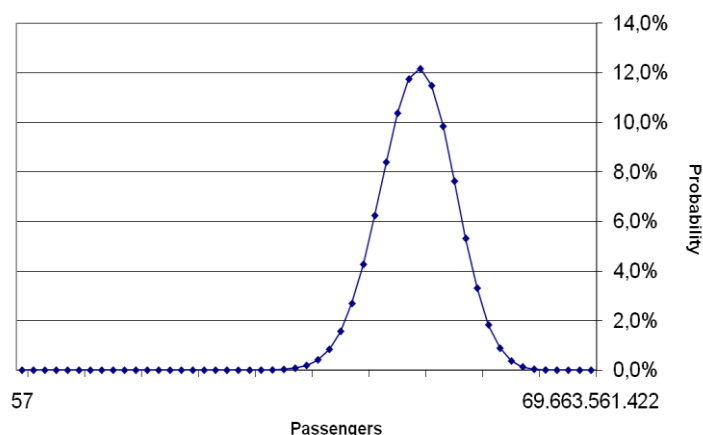


Fig. 6.1. – Probabilities for passenger activity in year 51 for a full service airport (top value of 131.165.696 Pax, with probability of 12,18 percent)

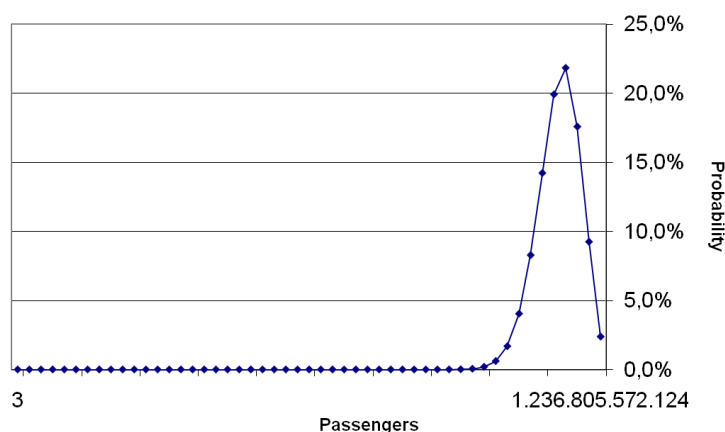


Fig. 6.2. – Probabilities for passenger activity in year 51 for a low-cost airport (top value of 249.659.939.356 Pax, with probability of 21,82 percent)

This approach lead to several extreme and very unlikely results in the final year of the lattice, at least in the one corresponding to a FSA, where a range between 37 and 460 MPax has a combined probability of 71,71 percent (even though the last value is very high, one must take into attention the fact that the prediction is done for half a century in the future, which may severely affect the accurateness of the results – for example, in year 25, a range between 9 and 46 MPax has a combined probability of 71,07 percent, a result that one might consider much more *realistic*).

On the other hand, in the lattice for the LCA the highest 10 results (being the lowest of these ten, 10.000 million Pax/year) have a combined probability of 99,73 percent, which is total unrealistic, since even the lowest of those values equals 1,5 times the current world population, and the highest value equals more than 180 times that value. Even at year 25, values ranging from 110 to 1500 million have a combined probability of 99,25 percent.

These results might indicate that this approach is not very good when used to model this kind of variables, that represent something physical (and not financial, for example) with high annual geometric growth rates, especially in a period as long as the one chosen in the model. So, the results obtained

from this lattice should be seen with care, since they very likely represent a situation not possible to translate to the real world.

Table 6.4. presents the results for this probabilistic scenario, for the same periods as the deterministic scenario, in order to allow comparisons between them.

Table 6.4. – Results for the flexible scenario.

Results	Type of Airport			
	Full Service		Low-Cost	
	FCF	CCF	FCF	CCF
NPV - 10 years	-788.264.337 €	-803.728.821 €	-525.717.713 €	-533.774.317 €
NPV - 20 years	-904.296.290 €	-921.653.637 €	-437.837.343 €	-493.343.129 €
NPV - 30 years	-938.924.165 €	-958.261.064 €	-275.311.157 €	-372.463.164 €
NPV - 40 years	-908.238.460 €	-935.167.531 €	-203.482.496 €	-318.466.040 €
NPV - 51 years	-873.880.395 €	-909.035.323 €	-169.990.641 €	-293.007.681 €

Once more the projects seem highly unprofitable, although not as much as in the inflexible scenarios, which may be a corroboration that developing an airport in a flexible way can add value to the project.

To make comparisons possible, data from Chamber MSc thesis was used again. The results from this second valuation are presented in Table 6.5.

Table 6.5. – Results for the flexible scenario, with new data.

Results	Type of Airport			
	Full Service		Low-Cost	
	FCF	CCF	FCF	CCF
NPV - 10 years	-679.352.213 €	-719.841.791 €	-304.078.217 €	-332.879.937 €
NPV - 20 years	-667.670.888 €	-719.959.768 €	380.199.555 €	164.481.086 €
NPV - 30 years	-572.227.778 €	-648.875.174 €	886.288.632 €	540.884.614 €
NPV - 40 years	-447.336.400 €	-554.941.637 €	1.109.289.605 €	708.525.372 €
NPV - 51 years	-356.257.048 €	-485.686.390 €	1.213.268.504 €	787.563.456 €

With these new inputs, the low-cost airport becomes profitable after only 16 years, considering the FCF model, and 18 years, using CCF model. In the remaining years studied, this LCA become highly profitable with NPVs close to the 1000 million euros mark.

The FSAs, even in this scenario with high net profit ratios, never become profitable, but the NPVs estimated are much less negative than the ones obtained using the original data obtained from CEGEA and TRENMO (2007).

6.3.1. OPTION VALUE

To estimate the value of considering flexibility when developing an airport project, the value of that option must be computed. In this model, that option is simply calculated by using equation (5.1).

The results are presented in Table 6.6., for the original inputs, and in Table 6.7. for the inputs by Chambers (2005).

Table 6.6. – Option value.

Results	Type of Airport			
	Full Service		Low-Cost	
	FCF	CCF	FCF	CCF
OV - 10 years	1.210.477.541 €	1.202.964.410 €	600.584.344 €	605.499.025 €
OV - 20 years	1.021.704.294 €	1.031.478.687 €	437.809.094 €	461.278.050 €
OV - 30 years	917.443.222 €	943.046.897 €	436.754.142 €	460.495.910 €
OV - 40 years	881.471.024 €	915.996.307 €	436.753.046 €	460.495.090 €
OV - 51 years	862.384.168 €	901.500.348 €	436.753.045 €	460.495.089 €

Table 6.7. – Option value, for the new data.

Results	Type of Airport			
	Full Service		Low-Cost	
	FCF	CCF	FCF	CCF
OV - 10 years	1.220.239.335 €	1.198.076.144 €	635.806.690 €	647.275.652 €
OV - 20 years	1.064.265.543 €	1.074.510.266 €	541.898.392 €	571.365.105 €
OV - 30 years	999.217.119 €	1.026.149.365 €	540.133.057 €	570.056.160 €
OV - 40 years	970.474.460 €	1.004.510.049 €	540.131.189 €	570.054.761 €
OV - 51 years	938.373.236 €	980.124.949 €	540.131.188 €	570.054.760 €

As demonstrated in Tables 6.6. and 6.7., the option of waiting before investing huge amounts of money in an over dimensioned airport is always rational, at least in financial terms. This is especially true in the first years of operation, when the airport is expected to function well below the maximum capacity of 50 MPax. After the first decades the option value starts to stabilize around one value, a trend that can be especially noticed in the LCA, where the option value at 10 years is practically the same as the option value at 51 years (the differences are below 0,5 percent).

6.3.2. ABANDONMENT OPTION

As explained in Chapter 5.1.2.2., another option was considered in the valuation process: abandon the project if traffic falls below a pre-determined threshold (defined as 1 MPax). If that happened the airport would close, and a total of 30 percent of the investment made would be salvaged.

Only the original cash flow data from CEGEA and TRENMO (2007) was used in this valuation.

Table 6.8. presents the NPV results for the abandonment option and Table 6.9. the option value, using the same methodology as in Chapter 6.3.1.

To compare the abandonment option with the original model that did not have that option, a new variable – abandonment option value – was estimated using equation 5.2. These results are presented in Table 6.10.

Table 6.8. – Results for the abandonment option.

Results	Type of Airport			
	Full Service		Low-Cost	
	FCF	CCF	FCF	CCF
NPV - 10 years	-781.903.302 €	-798.939.080 €	-525.680.324 €	-533.745.842 €
NPV - 20 years	-893.227.812 €	-912.356.946 €	-437.799.793 €	-493.314.524 €
NPV - 30 years	-926.921.531 €	-948.071.712 €	-275.273.607 €	-372.434.559 €
NPV - 40 years	-896.064.485 €	-924.849.484 €	-203.444.947 €	-318.437.434 €
NPV - 51 years	-861.675.222 €	-898.693.591 €	-169.953.091 €	-292.979.076 €

Table 6.9. – Option value for the abandonment option.

Results	Type of Airport			
	Full Service		Low-Cost	
	FCF	CCF	FCF	CCF
OV - 10 years	1.216.838.576 €	1.207.754.152 €	600.621.734 €	605.527.500 €
OV - 20 years	1.032.772.772 €	1.040.775.378 €	437.846.643 €	461.306.655 €
OV - 30 years	929.445.856 €	953.236.249 €	436.791.691 €	460.524.516 €
OV - 40 years	893.645.000 €	926.314.354 €	436.790.596 €	460.523.695 €
OV - 51 years	874.589.341 €	911.842.081 €	436.790.595 €	460.523.694 €

Table 6.10. – Abandonment option value.

	Type of Airport			
	Full Service		Low-Cost	
Results	FCF	CCF	FCF	CCF
AOV - 10 years	6.361.035 €	4.789.742 €	37.389 €	28.475 €
AOV - 20 years	11.068.477 €	9.296.691 €	37.550 €	28.605 €
AOV - 30 years	12.002.634 €	10.189.351 €	37.550 €	28.605 €
AOV - 40 years	12.173.975 €	10.318.047 €	37.550 €	28.605 €
AOV - 51 years	12.205.173 €	10.341.732 €	37.550 €	28.605 €

Due to the very low probabilities of achieving traffic patterns below 1 MPax (being the highest ones 0,0374 percent for the LCA and 0,8796 percent for the FSA), the abandonment option does not prove to be very valuable, since even the highest value of Table 6.10. (12.205.173 €) is only 1,44 percent of the original CAPEX made in that kind of airport. For the LCAs the abandonment option value is below 0,02 percent of the original CAPEX.

6.4. LOW-COST AIRPORT WITH LOWER ANNUAL GROWTH RATE

Since the annual growth rate used in the analysis produced very unrealistic results for the low-cost airport (the growth rate considered meant that traffic would double every four years and capacity would be exhausted after only 15 years), it was decided to make a new valuation using the annual growth rate as in the analysis regarding FSAs (which was estimated as the average annual geometric growth rate of a total of 221 European airports in the 2002-2007 period), which was considered to be a much more realistic growth rate in the long term.

This new valuation obviously produced the same traffic forecast as in the full service airport valuation already presented, but since construction costs are very different, NPV results should be also different.

In Tables 6.11. and 6.12. a comparison between the NPVs obtained by using data only regarding low-cost airports and data comprising all airports is presented, for both inflexible and flexible scenarios.

The option value is presented in Table 6.13.

Table 6.11. – Results for inflexible low-cost airports, with different annual growth rates.

Results	Data Source			
	Low-Cost Airports		All Airports	
	FCF	CCF	FCF	CCF
NPV - 10 years	-1.126.302.058 €	-1.139.273.342 €	-1.168.004.439 €	-1.172.909.262 €
NPV - 20 years	-875.646.437 €	-954.621.179 €	-1.123.133.696 €	-1.139.870.014 €
NPV - 30 years	-712.065.298 €	-832.959.075 €	-1.080.180.195 €	-1.107.901.958 €
NPV - 40 years	-640.235.543 €	-778.961.129 €	-1.039.062.015 €	-1.076.970.366 €
NPV - 51 years	-606.743.687 €	-753.502.770 €	-1.006.094.314 €	-1.051.908.728 €

Table 6.12. – Results for flexible low-cost airports, with different annual growth rates.

Results	Data Source			
	Low-Cost Airports		All Airports	
	FCF	CCF	FCF	CCF
NPV - 10 years	-525.717.713 €	-533.774.317 €	-317.457.531 €	-321.796.592 €
NPV - 20 years	-437.837.343 €	-493.343.129 €	-403.424.151 €	-409.097.172 €
NPV - 30 years	-275.311.157 €	-372.463.164 €	-435.505.227 €	-441.991.769 €
NPV - 40 years	-203.482.496 €	-318.466.040 €	-422.077.822 €	-431.878.859 €
NPV - 51 years	-169.990.641 €	-293.007.681 €	-402.838.945 €	-417.244.447 €

Table 6.13. – Option value for low-cost airports, with different annual growth rate.

Results	Data Source			
	Low-Cost Airports		All Airports	
	FCF	CCF	FCF	CCF
OV - 10 years	600.584.344 €	605.499.025 €	850.546.908 €	851.112.669 €
OV - 20 years	437.809.094 €	461.278.050 €	719.709.545 €	730.772.841 €
OV - 30 years	436.754.142 €	460.495.910 €	644.674.968 €	665.910.190 €
OV - 40 years	436.753.046 €	460.495.090 €	616.984.194 €	645.091.507 €
OV - 51 years	436.753.045 €	460.495.089 €	603.255.369 €	634.664.281 €

Considering the lower annual growth rates used in the new valuation, it was expected to obtain lower NPVs, since the airport operates under maximum capacity for considerably longer periods of time, which affects the level of cash flows generated at the airport.

In the inflexible scenario that assumption is true for all five periods considered, resulting in NPVs under -1000 million euros.

In the first two decades of the flexible scenario the results are different and the new NPVs values are higher than in the previous estimation. In the remaining 31 years newly estimated NPVs become lower as in the inflexible scenario.

These results make the option of waiting before making the total investment even more valuable than before, with an average increase in option value of around 200 million euros.

6.5. COMPARISON OF VALUATION MODELS

Valuing half-century long projects is always a difficult task, due to the uncertainties regarding the future and the choice of an adequate model is indispensable to correctly estimate the value of the project.

In this model the long-used free cash flow model, which demands an estimation of the level of financial leverage of the project,³⁹ and the more recent capital cash flow model, adequate for projects with high levels of financial leverage and/or variable capital structure, were used.

To assess how the two models of valuation used affect the final results, a simple numerical comparison (6.1) between the results of the two models was computed (Table 6.14.).

$$Difference = \frac{NPV_{CCF} - NPV_{FCF}}{NPV_{CCF}} \times 100 \quad (6.1)$$

Table 6.14. – Differences between the two models of valuation used for both types of airports.

	Type of Airport			
	Full Service		Low-Cost	
Difference	Inflexible	Flexible	Inflexible	Flexible
NPV - 10 years	0,396%	1,924%	1,139%	1,509%
NPV - 20 years	1,389%	1,883%	8,273%	11,251%
NPV - 30 years	2,364%	2,018%	14,514%	26,084%
NPV - 40 years	3,320%	2,880%	17,809%	36,105%
NPV - 51 years	4,102%	3,867%	19,477%	41,984%

³⁹ Changing in the capital structure throughout the life of the project, which would affect the discount rate, should also be considered. For simplification, this factor was not taken into account and it was assumed that the level of financial leverage (67 percent) would remain constant.

For the first 10 years the results appear to be quite similar in all the settings considered, but from that point onwards, the difference starts to enlarge, especially in the flexible LCA, where it reaches a whopping 42 percent difference after 51 years. In the case of the FSA those differences always stay under 5 percent, which is a margin of error much more acceptable.⁴⁰

To determine how would that difference between valuation models behave in the more *realistic* scenario of having low-cost airports with the same annual growth rate as other airports, another comparison, presented in Table 6.15., was done.

Table 6.15. – Differences between the two models of valuation used for low-cost airports, with different sources of traffic related data.

	Data Source			
	Low-Cost Airports		All Airports	
Difference	Inflexible	Flexible	Inflexible	Flexible
NPV - 10 years	1,139%	1,509%	0,418%	1,348%
NPV - 20 years	8,273%	11,251%	1,468%	1,387%
NPV - 30 years	14,514%	26,084%	2,502%	1,468%
NPV - 40 years	17,809%	36,105%	3,520%	2,269%
NPV - 51 years	19,477%	41,984%	4,355%	3,453%

With data source comprising all airports the results between the two models of valuation were greatly diminished to difference values even lower than the ones obtained in the FSA comparison presented in Table 6.14.

The use of very high annual growth rates once more appears to affect the final results in a great manner.

6.6. SENSITIVITY ANALYSIS

In order to determine which variables affect the results in a greater way, a sensitivity analysis, considering all variables, was run for all eight possible settings (Figure 5.1.)

As explained in Chapter 5.1.2.3., all variables were changed individually by ± 15 percent and, using equation 5.5 the effect of each variable in the final result was determined, through a sensitivity indicator.

Tables 6.16. and 6.17. presents the results of this sensitivity analysis for every variable for, respectively, the inflexible and flexible scenarios (highest three values for each column are represented on bold).

The complete results of this sensitivity analysis are presented in the appendices (Chapter A.8.) starting on page A.32.

⁴⁰ If all variables were correctly determined FCF and CCF results should be algebraically similar, as proven by Ruback (2002).

Table 6.16. – Sensitivity analysis for the inflexible scenarios.

Variable	Type of airport			
	FSA		LCA	
	FCF	CCF	FCF	CCF
Total cost (full service)	1,02	0,97	-	-
Total cost (low-cost)	-	-	1,70	1,37
Starting demand (Mpax)	0,15	0,11	0,33	0,21
Average annual growth rate (full service)	0,21	0,15	-	-
Average annual growth rate (low-cost)	-	-	0,61	0,37
Volatility (full service)	-	-	-	-
Volatility (low-cost)	-	-	-	-
Inflows (full service)	0,17	0,12	-	-
Inflows (low-cost)	-	-	0,85	0,69
Out\ Inflows (full service)	0,31	0,23	-	-
Out\ Inflows (low-cost)	-	-	2,56	1,56
Risk-free return rate	0,13	0,12	0,59	0,44
Asset beta	0,13	0,10	0,60	0,36
Market risk premium	0,13	0,10	0,59	0,36
Spread	0,03	-	0,15	-
Financial leverage	0,00	-	0,02	-
Corporate tax	0,04	0,04	0,19	0,18

Table 6.17. – Sensitivity analysis for the flexible scenarios.

	Type of airport			
	FSA		LCA	
Variable	FCF	CCF	FCF	CCF
Total cost (full service)	1,24	1,17	-	-
Total cost (low-cost)	-	-	4,14	2,37
Starting demand (Mpax)	0,13	0,14	0,09	0,12
Average annual growth rate (full service)	0,10	0,04	-	-
Average annual growth rate (low-cost)	-	-	2,98	1,15
Volatility (full service)	0,28	0,26	-	-
Volatility (low-cost)	-	-	1,50	0,77
Inflows (full service)	0,39	0,32	-	-
Inflows (low-cost)	-	-	3,28	1,51
Out\ Inflows (full service)	0,72	0,60	-	-
Out\ Inflows (low-cost)	-	-	9,86	4,57
Risk-free return rate	0,01	0,02	1,44	0,68
Asset beta	0,01	0,02	1,45	0,56
Market risk premium	0,01	0,02	1,45	0,56
Spread	0,00	-	0,37	-
Financial leverage	0,00	-	0,04	-
Corporate tax	0,00	0,03	0,46	0,38

Except for the FSA in the inflexible scenario, where the three most sensitive variables are total costs, outflows and average annual growth rate (in this order), the three most sensitive variables are total costs, outflows and inflows.

In the case of full service airports, final results do not seem to be affected in a great way by most of the variables (i.e., no matter how variables change, results will remain highly negative), since only costs have sensitivities greater than one. The financial variables have especially low effect on the final results, with sensitivities close to zero in the flexible scenario.

The low-cost airports present a completely different story, with most of the variables, including some of the financial ones, affecting the final results in a great manner. Outflows are especially sensitive, reaching values of 9,86. The one variable that has very low results is the level of financial leverage, with a maximum of 0,04.

For the sake of simplicity, and since in the FSAs' inflexible scenario average annual growth rate and inflows (third and fourth most sensitive variables, respectively) affect the results in practically the same way (a maximum total difference of about 30 million euros, has can be seen on Tables A.34. and A.35. of the appendices), the three most sensitive (total costs, inflows and outflows) variables in the other six settings will be used in all Monte Carlo simulations.

For the LCAs an additional Monte Carlo simulation will be run, including not only the aforementioned three most sensitive variables, but also the three most sensitive financial variables (risk-free return rate, asset beta and market risk premium).

6.6.1. DETERMINATION OF CORRELATIONS BETWEEN VARIABLES

Following the choice of the most influent variables and before running Monte Carlo simulations there was a need to establish correlations, if they existed, between the different variables.

As explained in Chapter 4.1.1.3. the exact assessment of the value of those correlations is not needed, since their purpose is not to produce high statistical accuracy but rather restraining the model from generating grossly inconsistent scenarios in large scale.

With that principle in mind, the following correlations were established:

- A positive correlation of 0,950 between all partial investment costs, i.e., if a partial investment has an increase in its costs the following partial investments have a very high probability of having also an increase in its costs. For example, if the initial investment on the FSA is 900 million euros instead of 846 million, there is a high probability that the next expansion for 20 MPax will cost more than the estimated 130 million euros;
- A positive correlation of 0,800 between the partial investment costs and the outflows, i.e., if investments costs increase, the outflows (which in this model is a percentage of the inflow values) have a relatively high probability of increasing and profit will consequently decrease. Using the same example as before, if the initial investment in the FSA increase to 900 million euros, operating expenses also have a tendency to increase, therefore outflows would have a value slightly higher than the initial estimation of 65 percent, and the net profit ratio would be lower than 35 percent.

Although there might be a correlation between investment costs and inflows (if investment cost increase, taxes for using the airport would probably also increase), it was decided not to include it in the simulation, since it might counter-balance the correlation between investment costs and outflows: if operating expenditures increase due to higher investment costs (for example, a 10 percent increase in costs leads to a 5 percent increase in operating expenditures), management could raise taxes (by 5 percent in this example) to increase inflows and maintain net profit ratios in the same level as before, which would lead to a situation very similar to the initial condition.

A way of avoiding this counter-balance effect would be to set a correlation coefficient between investment costs and inflows lower than the coefficient between investment costs and outflows (which is probably true since it might be difficult to reflect the increasing investment costs into the taxes the airport receives – if taxes increase too much passengers and airlines would simply avoid the airport, so there is a limit to the increase in their value). Using a correlation of 0,500 between investment costs and inflows lead to variation in the simulation's final results less than 0,5 percent different from the simulation without that correlation, so it was decided to exclude it from the simulations ran.

The final correlation possible between this set of variables was between outflows and inflows, which was already set in the model (outflows are defined as a percentage of inflows), so there was no need to set a new correlation.

For the other set of financial variables no correlations were set, due to the fact that there are no apparent relations between them.

6.7. MONTE CARLO SIMULATIONS⁴¹

6.7.1. ASSUMPTIONS

Because of the complex nature of the variables at hand, and considering that the purpose of running Monte Carlo simulations is not to obtain the exact probability of achieving positive NPVs, but only to give a rough estimate whether that is possible or not, there is no need to correctly assess the probabilistic distribution of the variables.

Therefore, simple triangular distributions, where the likeliest value is the deterministic value used in the previous valuations and the minimum and maximum values are a ± 15 percent variation of that value (the same variation used in the sensitivity analysis presented at Chapter 6.6.) were used.

Figure 6.3. shows an example of a triangular distribution. All the distributions used in the simulations are presented from pages A.41 to A.45 of the appendices.

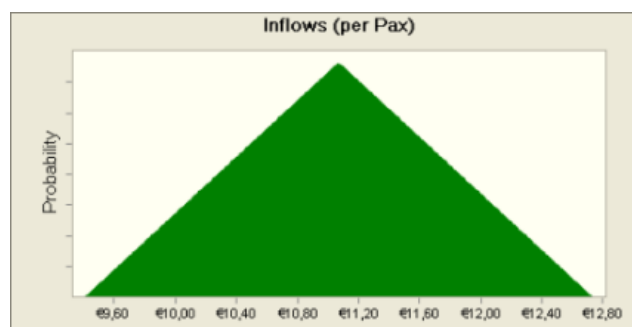


Fig. 6.3. – Example of a triangular distribution.

⁴¹ Only the most relevant results of the Monte Carlo simulations will be presented in this chapter. Other data produced by Crystal Ball – the software used to run the Monte Carlo simulations – is presented in Chapter A.9. (starting in page A.41) of the appendices.

6.7.2. FULL SERVICE AIRPORT RESULTS

A summary of the results of the Monte Carlo simulations ran for the FSA is presented in Table 6.18. More thorough results are presented in pages A.46 through A.51 of the appendices.

Table 6.18. – Monte Carlo simulation results for a full service airport.

Statistics	Forecast Values		
	FCF Inflexible	CCF Inflexible	FCF Flexible
Minimum	-2.162.120.834,84 €	-1.810.174.749 €	-1.202.288.852 €
Mean	-1.735.887.599 €	-2.210.031.268 €	-873.582.604 €
Maximum	-1.291.761.784,70 €	-1.396.502.010 €	-523.576.923 €
Statistics	CCF Flexible	FCF Option Value	CCF Option Value
Minimum	-1.222.243.997 €	752.460.019 €	789.489.333 €
Mean	-909.444.855 €	862.304.995 €	900.729.894 €
Maximum	-588.342.371 €	970.426.955 €	1.010.488.534 €

Using the mentioned correlated assumptions, with their triangular distributions, the probabilities of achieving positive NPVs is far from positive. Even in the best case scenario (flexible scenario valued by the FCF model) NPV is lower than -500 million euros and achieves values as low as -1400 million euros.

Option value is in the 750-1000 million euros range which indicates that even in the worst case scenarios the option to wait, and make partial investments instead of spending huge amounts of money up front is very valuable.

6.7.3. LOW-COST AIRPORT RESULTS

6.7.3.1. Simulation without Financial Variables

Running the Monte Carlo simulations for the LCAs without considering financial variables like asset beta or market risk premium, produced the results summarized in Table 6.19.

Once more, detailed results are presented on pages A.52 through A.57 of the appendices.

Table 6.19. – Monte Carlo simulation results for a low-cost airport.

Statistics	Forecast Values		
	FCF Inflexible	CCF Inflexible	FCF Flexible
Minimum	-1.095.370.850 €	-1.166.613.164 €	-627.905.498 €
Mean	-607.667.176 €	-754.234.979 €	-171.022.767 €
Maximum	-51.285.086 €	-291.031.904 €	362.069.255 €
Statistics	CCF Flexible	FCF Option Value	CCF Option Value
Minimum	-684.374.247 €	388.362.857 €	410.543.786 €
Mean	-293.953.520 €	436.644.409 €	460.281.458 €
Maximum	150.393.347 €	486.387.649 €	511.130.142 €

Opposite to the full service airports, low-cost airport projects appear to have small probabilities of becoming profitable after 51 years of operation.

Those positive NPVs appear only on the flexible scenarios, although in the inflexible scenario valued by the free cash flow model the maximum value almost reaches the break-even point.

While the CCF model has an extremely low (1,81 percent) probability of reaching a positive NPV, the FCF model has a more respectable probability of 16,85 percent, with a maximum value of 360 million euros and a 90th percentile value over 50 million euros.

Regarding option values, they do not reach such high values as in the full service airport simulations, but even in the worst case scenarios are around 400 million euros, a value large enough to again confirm the value of taking flexibility into account when developing an airport project.

6.7.3.2. Simulation with Financial Variables

Another set of simulations regarding LCAs were run, this time with the inclusion of three financial variables: asset beta, market risk premium, and risk-free return rate, all of them completely independent, i.e., no correlations involving these variables were fixed.

Table 6.20. presents the summarized results and in pages A.58 through A.68 are the complete results.

Table 6.20. – Monte Carlo simulation results for a low-cost airport, including financial variables.

Statistics	Forecast Values		
	FCF Inflexible	CCF Inflexible	FCF Flexible
Minimum	-1.135.629.144 €	-1.200.171.338 €	-628.842.769 €
Mean	-604.520.340 €	-751.593.587 €	-168.146.645 €
Maximum	78.974.487 €	-182.352.649 €	468.903.381 €
Statistics	CCF Flexible	FCF Option Value	CCF Option Value
Minimum	-676.548.067 €	356.577.468 €	378.877.928 €
Mean	-291.582.017 €	436.373.695 €	460.011.571 €
Maximum	233.230.307 €	517.943.680 €	539.882.479 €
Statistics	Equity Beta	Cost of Debt	Cost of Equity
Minimum	1,5144	5,948%	12,96%
Mean	1,7808	6,641%	16,21%
Maximum	2,0464	7,335%	19,88%
Statistics	Expected Asset Return	Weighted Average Cost of Capital	
Minimum	7,02%	7,25%	
Mean	8,46%	8,58%	
Maximum	10,05%	10,06%	

The consideration of changing financial variables in the simulations improves the probabilities of positive NPVs in the flexible scenarios (2,24 and 17,60 percent, for CCF and FCF models, respectively), and even the inflexible scenario has a probability of 0,015 percent of achieving a NPV over zero if the FCF model is used.

The general trend is that minimum and maximum values are further apart in this new set of simulations, increasing the range of possible results in all forecast values.

Option value falls around in almost the same range as in the simulation previously done, and their minimum and maximum values are also further apart than in the mentioned simulation.

6.7.4. COMPARISON BETWEEN SIMULATIONS WITH AND WITHOUT CORRELATING VARIABLES

In order to determine how the use, or not, of correlations between variables affect the simulations' final results, a number of new simulations were ran.

This comparison will only be made between the NPV results for both scenarios, and for both valuation models, i.e., option value was not taken into account.

6.7.4.1. Full Service Airport

The results of the Monte Carlo simulations with and without correlating variables for a FSA are presented in Table 6.21.

Table 6.21. – Comparison between Monte Carlo simulation results with and without correlations, for a full service airport.

Statistics (with correlations)	Forecast Values			
	FCF Inflexible	CCF Inflexible	FCF Flexible	CCF Flexible
Minimum	-2.162.120.834,84 €	-1.810.174.749 €	-1.202.288.852 €	-1.222.243.997 €
Mean	-1.735.887.599 €	-2.210.031.268 €	-873.582.604 €	-909.444.855 €
Maximum	-1.291.761.784,70 €	-1.396.502.010 €	-523.576.923 €	-588.342.371 €
Statistics (without correlations)	FCF Inflexible	CCF Inflexible	FCF Flexible	CCF Flexible
	FCF Inflexible	CCF Inflexible	FCF Flexible	CCF Flexible
Minimum	-1.997.134.858 €	-2.050.113.548 €	-1.122.347.128 €	-1.143.965.581 €
Mean	-1.736.870.515 €	-1.811.130.072 €	-874.334.977 €	-909.902.372 €
Maximum	-1.453.222.070 €	-1.555.209.562 €	-593.453.594 €	-650.095.520 €

The use of correlations between variables widens the range of forecast values, with a maximum of almost 400 million euros in the inflexible CCF model valuation, while the mean values remain almost the same.

6.7.4.2. Low-Cost Airport

Table 6.22. present the results for the comparison between the use, or not, of correlating variables in the Monte Carlo simulations regarding the LCAs.

Table 6.22. – Comparison between Monte Carlo simulation results with and without correlations, for a low-cost airport.

Statistics (with correlations)	Forecast Values			
	FCF Inflexible	CCF Inflexible	FCF Flexible	CCF Flexible
Minimum	-1.095.370.850 €	-1.166.613.164 €	-627.905.498 €	-684.374.247 €
Mean	-607.667.176 €	-754.234.979 €	-171.022.767 €	-293.953.520 €
Maximum	-51.285.086 €	-291.031.904 €	362.069.255 €	150.393.347 €
Statistics (without correlations)	FCF Inflexible	CCF Inflexible	FCF Flexible	CCF Flexible
	FCF Inflexible	CCF Inflexible	FCF Flexible	CCF Flexible
Minimum	-966.894.328 €	-1.047.801.750 €	-533.632.240 €	-598.010.819 €
Mean	-606.766.210 €	-753.608.191 €	-169.991.125 €	-293.116.232 €
Maximum	-197.299.291 €	-427.738.199 €	255.109.678 €	52.517.676 €

As in the case of the full service airports, the use of correlations between variables in the LCAs' Monte Carlo simulations widens the range of forecast values, and mean values still do not change significantly.

6.8. SUMMARY

The results produced by the model indicate that building an airport in the market conditions in which Portuguese airports operate might not be a very profitable endeavor.

Full service airports never have positive net present values, even in the most optimistic simulations. In fact, the highest value achieved for a FSA is below -500 million euros (-523.576.923 € for the flexible scenario valued by the FCF model).

On the other hand, airports aimed at serving low-cost carriers have slight chances of being a profitable project. But even in this case, only half of the scenarios have a chance (a very small one indeed, since its maximum value is 16,85 percent) of achieving positive NPVs, and all that positive values are obtained in the Monte Carlo simulations, since using the original input data, the model estimates that the highest value will be under -150 million euros (-169.990.641 € for the flexible scenario valued by the FCF model).

The sensitivity analysis conducted indicated that the variables that affected most the final results were the ones related with the costs of construction and the ones related to cash flows. The use of a different

data source for the cash flows (Chambers, 2005) seems to corroborate those results, since the only positive results obtained without using Monte Carlo simulations were computed by the model when using this new data.

The use of Monte Carlo simulations did not significantly changed the results, with the exception of the possible positive NPVs in the flexible scenarios for a low-cost airport, and all the different hypothesis within those simulations (use of correlations and financial variables in the case of LCAs) did not modify the results extensively.

Regardless all those negative results, the estimation of option values, i.e., the comparison between NPVs resulting from inflexible and flexible scenarios, indicate that the option to wait before making large investments is always very valuable, since its minimum value is over 400 million euros (in a LCA airport valued by the FCF model) and can achieve maximum values over 1200 million euros (in a FSA airport valued by the FCF model).

Concluding this chapter, one can argue that investing in an airport in these market conditions is indeed a risky business, and in order to develop a project that can create economic value a new paradigm is needed. That paradigm should not only focus on the flexible design of the airport, but also on improving economic efficiency by reducing costs during construction and operation, and by increasing revenues sources after the airport is opened, in order to maximize net profit ratios. Without those changes, an airport could hardly become a very attractive business for investors.

7

CONCLUSIONS

Uncertainty is now a major concept in almost every aspect of our society. Recent global and local crisis have underlined the crucial importance of flexibility in almost every scale, from the decisions each individual makes in their personal life, to the huge investments governments commit themselves to make.

Airports, and the aviation sector in general, have not been affected only by those factors transversal to all society, but also by other internal changes, like the still ongoing liberalization of the sector throughout the world, which makes an already unpredictable world into a tough challenge for airport planners.

In this thesis a new approach to tackle uncertainty, which takes flexibility into account when developing and managing an airport project, was discussed.

That flexibility, already put into action in various fields in the industry, was then evaluated by the real options theory – a derivation of the theoretical formulation for valuing contingent financial assets, such as options – which aims exactly to assess the value underlying such flexible designs. This new theory emerged as a contrast with the more traditional valuations models, like discounted cash flow, which fail to capture the strategic value inherent to each decision and do not support continuously arriving information regarding the implementation of the project.

However, such traditional valuation models should not be disregarded completely: like real options, they have their own virtues and drawbacks and the choice of using one model in detriment of another should be driven by the applicability to the problem under consideration.

Aiming to express the value of waiting before investing huge amounts of money into an infrastructure that has the chance of not being used in full capacity for years, a model comparing a range of different settings was developed.

The model had two main different scenarios: one inflexible and deterministic, where the investment to construct an airport was entirely made in the beginning of the project and a second one which had flexibility embedded in it, by making only small investments up front, and expanding the airport when traffic was enough to justify it.

The results produced by the model, although being very simplistic and thus only rough estimates of real cash flows generated at an airport, might be a proof, by comparison, that waiting for more information before committing to an investment might be a good idea, especially in a case where high levels of capital expenditures are needed.

Besides the waiting option, another option was also considered: abandon the airport if traffic fell below a pre-determined threshold. That solution proved not to be very valuable in the context of the entire project, since the probability of traffic falling below that mentioned threshold was very low, but should be also taken into account, because closing the airport and salvage what is possible from the initial investment might add more value to the project than continue operation regardless of what happens.

A way of improving the work developed in this thesis could be the consideration of other options embedded in the project, like the option to switch to a different type of airport (low-cost to full service or vice versa). This would lead to a whole new range of possible solutions that could add more value to the project.

Since the data used in the model was mostly based on studies regarding a sample of Portuguese airports investments and their operational results, the model showed that although less unprofitable, constructing a *flexible* airport is not still a very good investment: the huge amounts of capital investment needed for construction are not followed by large net profit ratios during operation, thus creating largely unattractive investments for project owners.

Ways of reducing capital expenditures and simultaneously improve profit margins are needed to ensure that possible new projects have higher possibilities of generating economic value.

Although used to value hypothetical airports located in Portugal, the model can be easily adapted to value other scenarios by simply changing the input variables, therefore, applications of this model with data from other countries rather than Portugal would be a valuable contribution to this subject, since it would allow comparisons between different realities.

REFERENCES

- Alexander, I.; Estache, A.; Oliver, A. (1999). *A Few Things Transport Regulators Should Know About Risk and the Cost of Capital*. Policy Research Working Paper 2151 - World Bank Institute: Governance, Regulation and Finance.
- Amram, M.; Kulatilaka, N. (1999). *Real Options: Managing Strategic Investment in an Uncertain World*, Financial Management Association Survey and Synthesis Series. Harvard Business School Press, Boston, USA.
- Black, F.; Scholes, M. (1973). *The Pricing of Options and Corporate Liabilities*. Journal of Political Economy 81:637-659.
- Block, S. (2007). *Are "Real Options" Actually Used in the Real World*. The Engineering Economist 52:255-267.
- Brealey, R. A.; Myers, S. C. (2000). *Principles of Corporate Finance*. Sixth Edition. McGraw-Hill, New York, USA.
- Button, K.; Costa, Á.; Reis, V. (2005). *How to Control Airlines Routes from the Supply Side: The Case of TAP*. Journal of Air Transportation 10 (3):50-72.
- Cardin, M.-A.; Neufville, R. d. (2008). *A Survey of State-of-the-Art Methodologies and a Framework for Identifying and Valuing Flexible Design Opportunities in Engineering Systems* Massachusetts Institute of Technology Working Paper (July 2008).
- Cardin, M.-A.; Neufville, R. d.; Dahlgren, J. (undated). *Extracting Value from Uncertainty: Proposed Methodology for Engineering Systems Design*.
- Cardin, M.-A.; Neufville, R. d.; Kazakidis, V. (2008). *A Process to Improve Expected Value of Mining Operations*. Mining Technology.
- Carvalho, L. C. A. d. (2005). *Uma Abordagem da Teoria de Opções Reais em Tempo Discreto*, Dissertation Submitted for the Degree of Mestre em Administração, Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, Brazil.
- Caves, R. E.; Gosling, G. D. (1999). *Strategic Airport Planning*. First Edition. Pergamon, Oxford, UK.
- Centro de Estudos de Gestão e Economia Aplicada - Faculdade de Economia e Gestão da Universidade Católica Portuguesa; TRENMO. (2007). *Avaliação Económica do Mérito Relativo da Opção "Portela + I" - Estudo de impacto da localização de um novo aeroporto na região de Lisboa*. Associação Comercial do Porto
- Chambers, R.-D. (2005). *Tackling Uncertainty in Airport Design: A Real Options Approach*, Dissertation Submitted for the Degree of Masters of Science in Technology and Policy, Massachusetts Institute of Technology, Cambridge, USA.
- Collins, K. (2001). *A Cost of Capital Guide*. ABN AMRO
- Copeland, T. E.; Antikarov, V. (2003). *Real Options: A Practitioner's Guide*. Texere.
- . (2005). *Real Options: Meeting the Georgetown Challenge*. Journal of Applied Corporate Finance 17 (2):32-51.
- Copeland, T. E.; Keenan, P. T. (1998). *How Much is Flexibility Worth?* The McKinsey Quarterly 1998 (2):38-49.

- Cox, J. C.; Ross, S. A.; Rubinstein, M. (1979). *Option Pricing: A Simplified Approach*. Journal of Financial Economics (September 1979).
- Damodaran, A. (2000). *The Promise of Real Options*. Journal of Applied Corporate Finance 13.2 (Summer 2000):29-44.
- . (2001). *Corporate Finance - Theory and Practice*. Second Edition, Wiley Series in Finance. John Wiley & Sons, Inc.
- . (2008). *Strategic Risk Taking: A Framework for Risk Management*. First Edition. Wharton Scholl Publishing, Upper Saddle River, USA.
- Dixit, A. K.; Pindyck, R. S. (1994). *Investment Under Uncertainty*. Princeton University Press, Princeton, USA.
- . (1995). *The Options Approach to Capital Investment*. Harvard Business Review 73 (May-June 1995):105-115.
- Fink, R. (2001). *Reality Check for Real Options*. CFO Magazine (September 2001).
- Greden, L.; Neufville, R. d.; Glicksman, L. (2005). *Management of Technology Investment Risk with Real Options-Based Design: A Case Study of an Innovative Building Technology*. 9th Annual Real Options Conference, Paris, France
- Hahn, W. J.; Dyer, J. S. (2008). *Discrete Time Modeling of Mean-Reverting Stochastic Processes for Real Option Valuation*. European Journal of Operational Research 184:534-548.
- He, K. (2007). *Real Options Application in Project Evaluation Practice*. Cost Engineering 49 (8):16-19.
- Herath, H. S. B.; Park, C. S. (2002). *Multi-Stage Capital Investment Opportunities as Compound Real Options*. The Engineering Economist 47 (1):1-27.
- Hodota, K. (2006). *R&D and Deployment Valuation of Intelligent Transportation Systems: A Case Example of the Intersection Collision Avoidance Systems*, Dissertation Submitted for the Degree of Master of Science in Transportation, Massachusetts Institute of Technology, Cambridge, USA.
- Kalos, M. H.; Whitlock, P. A. (1986). *Monte Carlo Methods - Volume I: Basics*. John Wiley & Sons, Inc., New York, USA.
- Kazda, A.; Caves, R. E. (2007). *Airport Design and Operation*. Second Edition. Elsevier, Oxford, UK.
- Kleimeier, S.; Megginson, W. L. (2001). *An Empirical Analysis of Limited Recourse Project Finance*. Working Paper - Submitted to the X International Tor Vergata Financial Conference on 'Competition, Financial Integration and Risks in the Global Economy' and to the Journal of Banking and Finance.
- Landau, D. P.; Binder, K. (2005). *A Guide to Monte Carlo Simulation in Statistical Physics*. Second Edition. Cambridge University Press, Cambridge, UK.
- Li, X.; Johnson, J. D. (2002). *Evaluate IT Investment Opportunities Using Real Options Theory*. Information Resources Management Journal 15 (3):32-47.

- Lin, J. (2008). *Exploring Flexible Strategies in Engineering Systems Using Screening Models: Applications to Offshore Petroleum Projects*, Dissertation Submitted for the Degree of Doctor of Philosophy in Engineering Systems, Massachusetts Institute of Technology, Cambridge, USA.
- Luehrman, T. A. (1998). *Investment Opportunities as Real Options: Getting Started on the Numbers*. Harvard Business Review (July - August 1998).
- Maseda, L. (2008). *Real Options Analysis of Flexibility in a Hospital Emergency Department Expansion Project, a Systems Approach*, Dissertation Submitted for the Degree of Master of Science in Engineering and Management, Massachusetts Institute of Technology, Cambridge, USA.
- McConnell, J. B. (2007). *A Life-Cycle Flexibility Framework for Designing, Evaluating and Managing "Complex" Real Options: Case Studies in Urban Transportation and Aircraft Systems*, Dissertation Submitted for the Degree of Doctor of Philosophy in Technology, Management and Policy, Massachusetts Institute of Technology, Cambridge, USA.
- Merton, R. C. (1973). *Theory of Rational Option Pricing*. The Bell Journal of Economics and Management Science 4 (1):141-183.
- Metropolis, N.; Ulam, S. (1949). *The Monte Carlo Method*. Journal of the American Statistical Association 44 (247):335-341.
- Miller, L. T.; Park, C. S. (2002). *Decision Making Under Uncertainty - Real Options to the Rescue?* The Engineering Economist 47 (2):105-150.
- Mittal, G. (2004). *Real Options Approach to Capacity Planning Under Uncertainty*, Dissertation Submitted for the Degree of Masters of Science in Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, USA.
- Myers, S. C. (1977). *Determinants of Corporate Borrowing*. Journal of Financial Economics 5:147-175.
- Neufville, R. d. (2000). *Airports in the 21st Century: Prospects for the Future*. Massachusetts Institute of Technology Working Paper.
- . (2002). *Architecting/Designing Engineering Systems Using Real Options*. Massachusetts Institute of Technology Working Paper Series (ESD-WP-2003-01.09).
- . (2003). *Real Options: Dealing with Uncertainty in Systems Planning and Design*. Integrated Assessment 4 (1):25-34.
- . (2004). *Uncertainty Management for Engineering Systems Planning and Design*. Engineering Systems Symposium.
- . (2006). *Accommodating Low Cost Airlines at Main Airports*. Draft for distribution at Transportation Research Board (TRB).
- . (2007). *Low-Cost Airports for Low-Cost Airlines: Flexible Design to Manage the Risks*. Journal of Transportation Planning and Technology (Special Issue).
- . (2008). *Building Airport Systems for the Next Generation*. Journal of the Academy of Engineering (Special Issue of Transportation Infrastructure):41-46.
- Neufville, R. d.; Scholtes, S. (2006). *Maximizing Value From Large-Scale Projects: Implementing Flexibility in Public - Private Partnerships*. Briefing Paper.

- Neufville, R. d.; Scholtes, S.; Wang, T. (2005). *Real Options by Spreadsheet: Parking Garage Case Example*. Manuscript IS/2004/22436.
- Ohama, D. (2008). *Using Design Flexibility and Real Options to Reduce Risk in Private Finance Initiatives: The Case of Japan*, Dissertation Submitted for the Degree of Master of Science in Technology and Policy, Massachusetts Institute of Technology, Cambridge, USA.
- Pitt, M. (2001). *Strategic Direction in the Airport Business: enabling or disabling?* Facilities 19 (3/4):150-156.
- Quispez-Asin, N. (2006). *Hybrid Lattice and Decision Analysis of Real Options: Application to a Supply Chain Strategy*, Dissertation Submitted for the Degree of Master of Science in Engineering Systems, Massachusetts Institute of Technology, Cambridge, USA.
- Ramírez, N. (2002). *Valuing Flexibility in Infrastructure Developments: The Bogota Water Supply Expansion Plan*, Dissertation Submitted for the Degree of Master of Science in Technology and Policy, Massachusetts Institute of Technology, Cambridge, USA.
- Ross, S. A.; Westerfield, R. W.; Jaffe, J. F. (1999). *Corporate Finance*. Fifth Edition, Finance Series. Irwin-McGraw-Hill.
- Ruback, R. S. (2002). *Capital Cash Flows: A Simple Approach to Valuing Risky Cash Flows*. Financial Management (Summer 2008):85-103.
- Santos, M. C. d.; Pinto, J. F. (2008). *Modelização da Avaliação de Projectos de Investimento em Infra-estruturas*.
- Savvides, S. C. (1994). *Risk Analysis in Investment Appraisal*. Project Appraisal 9 (1):3-18.
- Triantis, A. (2005). *Realizing the Potential of Real Options: Does Theory Meet Practice?* Journal of Applied Corporate Finance 17 (2):8-16.
- Wang, T. (2003). *Analysis of Real Options in Hydropower Construction Projects - A Case Study in China*, Dissertation Submitted for the Degree of Master of Science in Technology and Policy, Massachusetts Institute of Technology, Cambridge, USA.
- Wang, T.; Neufville, R. d. (2005). *Real Options 'in' Projects*. 9th Real Options Annual International Conference, June 2005, Paris, France.
- . (2006). *Identification of Real Options "in" Projects*. 16th Annual International Symposium of the International Council on Systems Engineering (INCOSE), Orlando, USA.

APPENDICES

A.1. PURPOSE OF AN AIRPORT MASTER PLAN

A.1.1. GENERAL PART

- A. An airport master plan is a guide for:
 - 1. Development of airport facilities, for aeronautical and non-aeronautical services
 - 2. Development of land uses for adjacent areas
 - 3. Environmental impact assessment
 - 4. Establishing of access requirements for the airport

- B. Beside others an airport master plan is used to:
 - 1. Provide guidance for long and short term planning
 - 2. Identify potential problems and opportunities
 - 3. Be a tool for financial planning
 - 4. Serve as basis for negotiation between the airport management and concessionaires

A.1.2. TYPES OF ACTIONS DURING THE AIRPORT MASTER PLANNING

- A. Policy/co-ordinative planning:
 - 1. Setting project objectives and aims
 - 2. Preparing project work programs, schedules and budgets
 - 3. Preparing an evaluation and decision format
 - 4. Establishing co-ordination and monitoring procedures
 - 5. Establishing data management and information system
- B. Economic planning
 - 1. Preparing market outlooks and market forecasts
 - 2. Determining cost benefit of alternative schemes
 - 3. Preparing assessment of catchment area impact study of alternative schemes
- C. Physical planning
 - 1. System of air traffic control and airspace organization
 - 2. Airfield configuration including approach zones
 - 3. Terminal complex
 - 4. Utility communication network and circulation
 - 5. Support and service facilities
 - 6. Ground access system
 - 7. Over-all land use patterns
- D. Environmental planning
 - 1. Preparing of an environmental impact airport assessment
 - 2. Project development of the impact area
 - 3. Determining neighboring communities' attitudes and opinions
- E. Financial planning
 - 1. Determining of airport development financing

2. Preparing financial feasibility study or alternative
3. Preparing preliminary financial plans for the finally approved project alternative

A.1.3. STEPS IN THE PLANNING PROCESS

- A. Preparing a master planning work programme
- B. Inventory and documentation of existing conditions
- C. Future air traffic demand forecast
- D. Determining gross facility requirements and preliminary time-phased development of same
- E. Assessing existing and potential constraints
- F. Agree upon relative importance or priority of various elements:
 1. Airport type
 2. Constraints
 3. Political and other considerations
- G. Development of several conceptual or master plan alternatives for purpose of comparative analysis
- H. Review and screen alternative conceptual plans. Provide all interested parties with an opportunity to test each alternative
- I. Selection of the preferred alternative, development of this alternative and preparing it in final form

A.1.4. PLAN UPDATE RECOMMENDATIONS

- A. Master plan and/or specific elements should be reviewed at least biennially and adjusted as appropriate to reflect conditions at the time of review
- B. Master plan should be thoroughly evaluated and modified every five years, or more often if changes in economic, operational, environmental and financial conditions indicate an earlier need for such revision

Source: *Airport Planning Manual, Part 1 Master Planning*, (ICAO Doc 9184-AN/902), quoted by Kazda and Caves (2007)

A.2. EXAMPLES OF DIFFERENCES BETWEEN TRAFFIC FORECASTS AND ACTUAL TRAFFIC

Table A.1. – Traffic forecast for Lisbon Airport (Portela) by different entities.

Source: Adapted from CEGEA and TRENMO (2007) and Wang and Neufville (2005)

Year	Actual Traffic (MPax)	Forecasted Traffic by Entity (MPax)					
		Parsons (2002)		ADP (1999)		Manchester (1999)	
		Forecast	Variation	Forecast	Variation	Forecast	Variation ¹
1997	6,6	-	-	-	-	-	-
2000	9,2	-	-	8,8	-4,35%	8,7 - 9,3	-2,17%
2001	9,4	9,2	-2,13%	-	-	9,0 - 10,1	1,60%
2002	9,4	9,7	3,19%	-	-	9,4 - 10,9	7,98%
2005	11,3	11,6	2,65%	11,2	-0,88%	10,5 - 13,7	7,08%
2006	12,3	12,1	-1,63%	-	-	10,9 - 14,8	4,47%
2007	13,4	12,7	-5,22%	-	-	11,4 - 15,6	0,75%
2010	-	14,4	-	13,8	-	12,8 - 20,1	-
2015	-	16,8	-	16,8	-	15,6 - 30,0	-
2020	-	-	-	19,9	-	19	-

Year	Actual Traffic (MPax)	Forecasted Traffic by Entity (MPax)					
		IATA (1998)		IATA (1992)		TAMS (1982)	
		Forecast	Variation	Forecast	Variation	Forecast	Variation
1997	6,6	-	-	6,5	-1,52%	-	-
2000	9,2	-	-	-	-	-	-
2001	9,4	8,4	-10,64%	-	-	-	-
2002	9,4	-	-	8,4	-10,64%	-	-
2005	11,3	-	-	-	-	-	-
2006	12,3	10,5	-14,63%	-	-	-	-
2007	13,4	-	-	10,8	-19,40%	-	-
2010	-	-	-	-	-	23,0	-
2015	-	15,6	-	-	-	-	-
2020	-	-	-	-	-	-	-

¹ Based on the average values of the range of predicted forecasts.

Table A.2. – Difference between traffic forecast (one and ten years earlier)
for American domestic flights and actual enplanements.

Source: Ohama (2008), quoting the
FAA Aerospace Forecasts Fiscal Years 2006-2017 report (2006)

Year being forecast	Forecast published one year earlier	Forecast published ten years earlier
1995	-2,2%	-11,4%
1996	1,8%	-12,2%
1997	-1,4%	-17,4%
1998	-1,7%	-14,9%
1999	1,3%	-9,9%
2000	1,4%	-5,5%
2001	-4,6%	-4,7%
2002	4,4%	-14,5%
2003	-0,9%	-12,5%
2004	0,2%	-20,0%
2005	3,2%	-13,9%
Mean Error	0,1%	-12,5%

A.3. ASSUMPTIONS OF THE CAPITAL ASSET PRICING MODEL

The main assumptions of the CAPM are (adapted from (Collins, 2001):

- Investors aim to maximize economic utility;
- Investors are risk-averse, i.e., investors seek to minimise risk for any given level of return;
- Investors cannot influence prices, they are price takers;
- Investors can lend and borrow unlimited under the risk-free rate of interest;
- Rational investors hold fully diversified portfolios;
- All investors have identical expectations about variables such as expected rates of return and risk;
- There are no transaction costs;
- There are no investment-related taxes;
- All information is available at the same time to all investors;
- The market has perfect divisibility and liquidity.

A.4. ASSUMPTIONS OF THE BLACK-SCHOLES MODEL

The main assumptions of the BS model are (Ross *et al.*, 1999):

- a. There are no penalties for or restrictions on short selling;
- b. Transaction costs and taxes are zero;
- c. The option is European;
- d. The stock pays no dividends;
- e. The stock price is continuous, that is, there are no jumps;
- f. The market operate continuously;
- g. The short-term interest rate is know and constant;
- h. The stock price is “lognormally” distributed.

A.5. FULL INVESTMENT COSTS ON THE TWO TYPES OF AIRPORTS CONSIDERED

Table A.3. – Full investments on a full service airport (all prices in Euros).
Source: Adapted from CEGEA and TRENMO (2007)

Capacity (MPax)	Operations Area (1)	Terminal (2)	Technical Equipment (3)	Support Systems (4)	Environmental Systems (5)
15	185.000.000	402.000.000	24.000.000	175.000.000	5.000.000
20	43.000.000	75.000.000	1.500.000	2.500.000	0
25	49.000.000	95.000.000	1.800.000	2.500.000	0
30	155.000.000	160.000.000	2.500.000	2.500.000	0
35	32.000.000	75.000.000	1.200.000	2.500.000	0
40	33.000.000	95.000.000	1.200.000	2.500.000	0
45	43.000.000	105.000.000	1.500.000	2.500.000	0
50	49.000.000	110.000.000	1.800.000	2.500.000	0

Capacity (MPax)	Unexpected Costs (7%)	Partial Investment	Total Investment	Cost/ Passenger
15	55.370.000	846.370.000	846.370.000	56
20	8.540.000	130.540.000	976.910.000	49
25	10.381.000	158.681.000	1.135.591.000	45
30	22.400.000	342.400.000	1.477.991.000	49
35	7.749.000	118.449.000	1.596.440.000	46
40	9.219.000	140.919.000	1.737.359.000	43
45	10.640.000	162.640.000	1.899.999.000	42
50	11.431.000	174.731.000	2.074.730.000	41

(1) Including runways, taxiways, parking positions for planes, etc. Partial investment costs increase at 30 MPax due to the construction of a second runway.

(2) Including luggage processing facilities, offices, etc.

(3) Including control tower, police station, firemen headquarters, etc.

(4) Including parking places, fuel storage facilities, etc.

(5) Including air, water and noise monitoring systems.

Table A.4. – Full investments on a low-cost airport (all prices in Euros).
Source: Adapted from CEGEA and TRENMO (2007)

Capacity (MPax)	Operations Area (1)	Terminal (2)	Technical Equipment (3)	Support Systems (4)	Environmental Systems (5)
15	120.000.000	33.000.000	15.000.000	100.000.000	5.000.000
20	32.000.000	33.000.000	1.200.000	2.500.000	0
25	33.000.000	39.000.000	1.200.000	2.500.000	0
30	43.000.000	39.000.000	1.500.000	2.500.000	0
35	49.000.000	45.000.000	1.800.000	2.500.000	0
40	155.000.000	45.000.000	2.500.000	2.500.000	0
45	32.000.000	33.000.000	1.200.000	2.500.000	0
50	33.000.000	39.000.000	1.200.000	2.500.000	0

Capacity (MPax)	Unexpected Costs (7%)	Partial Investment	Total Investment	Cost/ Passenger
15	19.110.000	292.110.000	292.110.000	58
20	4.809.000	73.509.000	365.619.000	37
25	5.299.000	80.999.000	446.618.000	30
30	6.020.000	92.020.000	538.638.000	27
35	6.881.000	105.181.000	643.819.000	26
40	14.350.000	219.350.000	863.169.000	29
45	4.809.000	73.509.000	936.678.000	27
50	5.299.000	80.999.000	1.017.677.000	25

(1) Including runways, taxiways, parking positions for planes, etc. Partial investment costs increase at 30 MPax due to the construction of a second runway.

(2) Including luggage processing facilities, offices, etc.

(3) Including control tower, police station, firemen headquarters, etc.

(4) Including parking places, fuel storage facilities, etc.

(5) Including air, water and noise monitoring systems.

A.6. RESULTS FOR THE INFLEXIBLE SCENARIO

A.6.1. FULL SERVICE AIRPORT

Table A.5. – Results for the inflexible scenario for a full service airport, including the first and the final years considered in the analysis, and the years when airport capacity is first exceed. All prices in euros (€).

Year (1)	0	1	2	3	4	5	6
Passenger Movements (2)	2.000.000	2.162.103	2.337.345	2.526.791	2.731.591	2.952.991	3.192.335
Capacity Exceed? (3)	No	No	No	No	No	No	No
Expected Passenger Inflows (4)	22.140.000	23.934.482	25.874.409	27.971.571	30.238.711	32.689.606	35.339.150
Expected Passenger Outflows (5)	14.391.000	15.557.413	16.818.366	18.181.521	19.655.162	21.248.244	22.970.448
Expected Passenger Cash Flows (6)	7.749.000	8.377.069	9.056.043	9.790.050	10.583.549	11.441.362	12.368.703
Discount Factor (FCF) (7)	1,0000	0,9210	0,8482	0,7812	0,7195	0,6627	0,6103
Presente Value Cash Flows (FCF) (8)	7.749.000	7.715.236	7.681.618	7.648.147	7.614.823	7.581.643	7.548.608
Revenue Taxes (9)	0	0	0	0	0	0	3.401.393
Expected Cash Flows (after taxes) (10)	7.749.000	8.377.069	9.056.043	9.790.050	10.583.549	11.441.362	8.967.309
Discount Factor (CCF) (11)	1,0000	0,9220	0,8500	0,7837	0,7226	0,6662	0,6142
Presente Value Cash Flows (CCF) (12)	7.749.000	7.723.502	7.698.088	7.672.758	7.647.511	7.622.347	5.508.017

(1)	41	42	46	47	48	49	50
(2)	48.835.204	52.793.374	72.104.949	77.949.169	84.267.072	91.097.052	98.480.611
(3)	No	Yes	Yes	Yes	Yes	Yes	Yes
(4)	540.605.704	553.500.000	553.500.000	553.500.000	553.500.000	553.500.000	553.500.000
(5)	351.393.707	359.775.000	359.775.000	359.775.000	359.775.000	359.775.000	359.775.000
(6)	189.211.996	193.725.000	193.725.000	193.725.000	193.725.000	193.725.000	193.725.000
(7)	0,0342	0,0315	0,0227	0,0209	0,0192	0,0177	0,0163
(8)	6.478.738	6.109.203	4.395.548	4.048.276	3.728.441	3.433.874	3.162.580
(9)	52.033.299	53.274.375	53.274.375	53.274.375	53.274.375	53.274.375	53.274.375
(10)	137.178.697	140.450.625	140.450.625	140.450.625	140.450.625	140.450.625	140.450.625
(11)	0,0358	0,0330	0,0238	0,0220	0,0203	0,0187	0,0172
(12)	4.907.909	4.632.930	3.347.684	3.086.503	2.845.698	2.623.681	2.418.985

A.6.2. LOW-COST AIRPORT

Table A.6. – Results for the inflexible scenario for a low-cost airport, including the first and the final years considered in the analysis, and the years when airport capacity is first exceed. All prices in euros (€).

Year (1)	0	1	2	3	4	5	6
Passenger Movements (2)	2.000.000	2.456.551	3.017.322	3.706.103	4.552.117	5.591.254	6.867.602
Capacity Exceed? (3)	No	No	No	No	No	No	No
Expected Passenger Inflows (4)	19.120.000	23.484.631	28.845.601	35.430.349	43.518.236	53.452.390	65.654.271
Expected Passenger Outflows (5)	14.340.000	17.613.473	21.634.200	26.572.762	32.638.677	40.089.293	49.240.703
Expected Passenger Cash Flows (6)	4.780.000	5.871.158	7.211.400	8.857.587	10.879.559	13.363.098	16.413.568
Discount Factor (FCF) (7)	1,0000	0,9210	0,8482	0,7812	0,7195	0,6627	0,6103
Presente Value Cash Flows (FCF) (8)	4.780.000	5.407.305	6.116.934	6.919.692	7.827.801	8.855.085	10.017.185
Revenue Taxes (9)	0	0	0	0	0	0	4.513.731
Expected Cash Flows (after taxes) (10)	4.780.000	5.871.158	7.211.400	8.857.587	10.879.559	13.363.098	11.899.837
Discount Factor (CCF) (11)	1,0000	0,9220	0,8500	0,7837	0,7226	0,6662	0,6142
Presente Value Cash Flows (CCF) (12)	4.780.000	5.413.099	6.130.049	6.941.959	7.861.403	8.902.625	7.309.272

(1)	15	16	46	47	48	49	50
(2)	43.698.621	53.673.953	25.623.535.018	31.472.764.611	38.657.231.002	47.481.736.263	58.320.661.364
(3)	No	Yes	Yes	Yes	Yes	Yes	Yes
(4)	417.758.814	478.000.000	478.000.000	478.000.000	478.000.000	478.000.000	478.000.000
(5)	313.319.110	358.500.000	358.500.000	358.500.000	358.500.000	358.500.000	358.500.000
(6)	104.439.703	119.500.000	119.500.000	119.500.000	119.500.000	119.500.000	119.500.000
(7)	0,2910	0,2680	0,0227	0,0209	0,0192	0,0177	0,0163
(8)	30.389.417	32.024.456	2.711.410	2.497.195	2.299.903	2.118.198	1.950.849
(9)	28.720.918	32.862.500	32.862.500	32.862.500	32.862.500	32.862.500	32.862.500
(10)	75.718.785	86.637.500	86.637.500	86.637.500	86.637.500	86.637.500	86.637.500
(11)	0,2957	0,2726	0,0238	0,0220	0,0203	0,0187	0,0172
(12)	22.389.093	23.618.971	2.065.032	1.903.921	1.755.380	1.618.428	1.492.160

A.7. RESULTS FOR THE FLEXIBLE SCENARIO

A.7.1. FULL SERVICE AIRPORT

Table A.7. – Binomial lattice for expected passenger movements for a full service airport.

Year 0	Year 1	Year 2	Year 29	Year 30	Year 31	Year 49	Year 50
2.000.000	2.465.298	3.038.848	861.739.278	1.062.222.270	1.309.347.477	56.515.315.920	69.663.561.422
	1.622.522	2.000.000	567.148.596	699.095.288	861.739.278	37.195.220.065	45.848.659.879
		1.316.288	373.265.486	460.105.419	567.148.596	24.479.813.536	30.175.023.639
			245.662.466	302.815.653	373.265.486	16.111.244.125	19.859.512.885
			161.681.295	199.296.327	245.662.466	10.603.519.789	13.070.420.648
			106.409.586	131.165.696	161.681.295	6.978.643.676	8.602.219.848
			70.032.838	86.325.925	106.409.586	4.592.952.955	5.661.499.986
			46.091.697	56.814.896	70.032.838	3.022.824.753	3.726.082.646
			30.334.977	37.392.387	46.091.697	1.989.454.188	2.452.299.200
			19.964.785	24.609.578	30.334.977	1.309.347.477	1.613.966.177
			13.139.705	16.196.648	19.964.785	861.739.278	1.062.222.270
			8.647.819	10.659.728	13.139.705	567.148.596	699.095.288
			5.691.511	7.015.636	8.647.819	373.265.486	460.105.419
			3.745.834	4.617.300	5.691.511	245.662.466	302.815.653
			2.465.298	3.038.848	3.745.834	161.681.295	199.296.327
			1.622.522	2.000.000	2.465.298	106.409.586	131.165.696
			1.067.853	1.316.288	1.622.522	70.032.838	86.325.925
			702.801	866.307	1.067.853	46.091.697	56.814.896
			462.544	570.155	702.801	30.334.977	37.392.387
			304.421	375.244	462.544	19.964.785	24.609.578
			200.353	246.965	304.421	13.139.705	16.196.648
			131.861	162.538	200.353	8.647.819	10.659.728
			86.784	106.974	131.861	5.691.511	7.015.636
			57.116	70.404	86.784	3.745.834	4.617.300
			37.591	46.336	57.116	2.465.298	3.038.848
			24.740	30.496	37.591	1.622.522	2.000.000
			16.283	20.071	24.740	1.067.853	1.316.288
			10.716	13.209	16.283	702.801	866.307
			7.053	8.694	10.716	462.544	570.155
			4.642	5.722	7.053	304.421	375.244
				3.766	4.642	200.353	246.965
					3.055	131.861	162.538
						86.784	106.974
						57.116	70.404
						37.591	46.336
						24.740	30.496
						16.283	20.071
						10.716	13.209
						7.053	8.694
						4.642	5.722
						3.055	3.766
						2.011	2.478
						1.323	1.631
						871	1.074
						573	707
						377	465
						248	306
						163	201
						108	133
						71	87
							57

Table A.8. – Binomial lattice for the probabilities associated with each node for a full service airport.

[illegible]

Table A.9. – Binomial lattice for the need for expansion for a full service airport.

[illegible]

Relative to 2007, the estimated increase for the total investment need for a full service import and process in services is 17%.

[illegible]

Table A.11. – Binomial lattice for the partial investment need for a full service airport. All prices in euros (€).

[illegible]

[illegible]

Table A.13. – Binomial lattice for the expected cash flows for a full service airport. All prices in euros (€).

Year 0	Year 1	Year 2	Year 29	Year 30	Year 31	Year 49	Year 50
-838.621.000	9.551.799	11.774.018	193.725.000	193.725.000	193.725.000	193.725.000	193.725.000
	6.286.460	7.749.000	193.725.000	193.725.000	193.725.000	193.725.000	193.725.000
		5.099.958	193.725.000	193.725.000	193.725.000	193.725.000	193.725.000
			193.725.000	193.725.000	193.725.000	193.725.000	193.725.000
			193.725.000	193.725.000	193.725.000	193.725.000	193.725.000
			193.725.000	193.725.000	193.725.000	193.725.000	193.725.000
			193.725.000	193.725.000	193.725.000	193.725.000	193.725.000
			193.725.000	193.725.000	193.725.000	193.725.000	193.725.000
			178.582.280	193.725.000	193.725.000	193.725.000	193.725.000
			117.532.869	144.876.802	178.582.280	193.725.000	193.725.000
			-226.205.439	-79.381.192	117.532.869	193.725.000	193.725.000
			-291.490.213	-55.695.089	-226.205.439	193.725.000	193.725.000
			-97.034.025	-117.379.886	-291.490.213	193.725.000	193.725.000
			22.051.759	27.182.083	-97.034.025	193.725.000	193.725.000
			14.513.234	17.889.727	22.051.759	193.725.000	193.725.000
			9.551.799	11.774.018	14.513.234	193.725.000	193.725.000
			6.286.460	7.749.000	9.551.799	193.725.000	193.725.000
			4.137.396	5.099.958	6.286.460	193.725.000	193.725.000
			2.723.003	3.356.507	4.137.396	178.582.280	193.725.000
			1.792.128	2.209.065	2.723.003	117.532.869	144.876.802
			1.179.479	1.453.883	1.792.128	77.353.561	95.349.808
			776.267	956.865	1.179.479	50.909.787	62.753.911
			510.895	629.755	776.267	33.505.975	41.301.114
			336.243	414.469	510.895	22.051.759	27.182.083
			221.296	272.781	336.243	14.513.234	17.889.727
			145.645	179.529	221.296	9.551.799	11.774.018
			95.855	118.156	145.645	6.286.460	7.749.000
			63.087	77.764	95.855	4.137.396	5.099.958
			41.520	51.180	63.087	2.723.003	3.356.507
			27.326	33.684	41.520	1.792.128	2.209.065
			17.985	22.169	27.326	1.179.479	1.453.883
				14.590	17.985	776.267	956.865
					11.836	510.895	629.755
						336.243	414.469
						221.296	272.781
						145.645	179.529
						95.855	118.156
						63.087	77.764
						41.520	51.180
						27.326	33.684
						17.985	22.169
						11.836	14.590
						7.790	9.602
						5.127	6.320
						3.374	4.159
						2.221	2.737
						1.462	1.802
						962	1.186
						633	780
						417	514
						274	338
							222

Table A.14. – Binomial lattice for the probability weighted expected cash flows for a full service airport.
All prices in euros (€).

[illegible]

Table A.15. – Flexible scenario free cash flows results for a full service airport.
All prices in euros (€).

	Year 0	Year 1	Year 2	Year 29	Year 30	Year 31	Year 49	Year 50
CF (1)	-838.621.000	8.551.788	9.437.744	-11.013.926	40.152.216	8.087.508	166.579.349	168.305.079
Discount Factor	1,0000	0,9210	0,8482	0,0919	0,0847	0,0780	0,0177	0,0163
PV CF (2)	-838.621.000	7.876.151	8.005.388	-1.012.508	3.399.562	630.646	2.952.704	2.747.597

(1) Cash Flows

(2) Present Value Cash Flows

Table A.16. – Flexible scenario capital cash flows results for a full service airport.
All prices in euros (€).

	Year 0	Year 1	Year 2	Year 29	Year 30	Year 31	Year 49	Year 50
Revenue taxes	0	2.351.742	2.595.379	0	11.041.859	2.224.065	45.809.321	46.283.897
CF (1)	-838.621.000	6.200.046	6.842.364	-11.013.926	29.110.356	5.863.443	120.770.028	122.021.182
Discount Factor	1,0000	0,9220	0,8500	0,0948	0,0874	0,0806	0,0187	0,0172
PV CF (2)	-838.621.000	5.716.328	5.816.350	-1.044.445	2.545.149	472.651	2.256.039	2.101.575

(1) Cash Flows after taxes

(2) Present Value Cash Flows

Table A.17. – Binomial lattice for the abandonment option for a full service airport.

[illegible]

Table A.18. – Flexible scenario free cash flows results for the abandonment option for a full service airport.
All prices in euros (€).

	Year 0	Year 1	Year 2	Year 29	Year 30	Year 31	Year 49	Year 50
CF (1)	-838.621.000	8.551.788	9.437.744	-10.713.630	40.632.978	10.713.630	166.633.246	168.305.079
Discount Factor	1,0000	0,9210	0,8482	0,0919	0,0847	0,0919	0,0177	0,0163
PV CF (2)	-838.621.000	7.876.151	8.005.388	-984.902	3.440.267	-984.902	2.953.659	2.747.597

(1) Cash Flows

(2) Present Value Cash Flows

Table A.19. – Flexible scenario capital cash flows results for the abandonment option for a full service airport.
All prices in euros (€).

	Year 0	Year 1	Year 2	Year 29	Year 30	Year 31	Year 49	Year 50
Revenue taxes	0	2.351.742	2.595.379	0	11.174.069	2.293.796	45.824.143	46.283.897
CF (1)	-838.621.000	6.200.046	6.842.364	-10.713.630	29.458.909	6.047.281	120.809.104	122.021.182
Discount Factor	1,0000	0,9220	0,8500	0,0948	0,0874	0,0806	0,0187	0,0172
PV CF (2)	-838.621.000	5.716.328	5.816.350	-1.015.968	2.575.624	487.470	2.256.769	2.101.575

(1) Cash Flows after taxes

(2) Present Value Cash Flows

A.7.2. LOW-COST AIRPORT

Table A.20. – Binomial lattice for expected passenger movements for a low-cost airport.

Year 0	Year 1	Year 2	Year 29	Year 30	Year 31	Year 49	Year 50
2.000.000	2.611.292	3.409.423	4.570.539.109	5.967.505.915	7.791.449.980	947.274.844.391	1.236.805.572.124
	1.531.809	2.000.000	2.681.121.973	3.500.596.068	4.570.539.109	555.680.487.449	725.521.982.630
		1.173.219	1.572.771.803	2.053.483.148	2.681.121.973	325.967.490.808	425.598.136.961
			922.602.988	1.204.592.863	1.572.771.803	191.215.649.035	249.659.939.356
			541.207.741	706.625.699	922.602.988	112.168.929.316	146.452.909.226
			317.477.639	414.513.396	541.207.741	65.799.367.193	85.910.677.845
			186.235.421	243.157.524	317.477.639	38.598.538.378	50.396.025.636
			109.247.480	142.638.530	186.235.421	22.642.271.932	29.562.790.838
			64.085.617	83.673.127	109.247.480	13.282.173.361	17.341.815.969
			37.593.236	49.083.457	64.085.617	7.791.449.980	10.172.875.177
			22.052.552	28.792.825	37.593.236	4.570.539.109	5.967.505.915
			12.936.238	16.890.147	22.052.552	2.681.121.973	3.500.596.068
			7.588.521	9.907.922	12.936.238	1.572.771.803	2.053.483.148
			4.451.499	5.812.082	7.588.521	922.602.988	1.204.592.863
			2.611.292	3.409.423	4.451.499	541.207.741	706.625.699
			1.531.809	2.000.000	2.611.292	317.477.639	414.513.396
			898.574	1.173.219	1.531.809	186.235.421	243.157.524
			527.112	688.222	898.574	109.247.480	142.638.530
			309.209	403.717	527.112	64.085.617	83.673.127
			181.385	236.824	309.209	37.593.236	49.083.457
			106.402	138.923	181.385	22.052.552	28.792.825
			62.417	81.494	106.402	12.936.238	16.890.147
			36.614	47.805	62.417	7.588.521	9.907.922
			21.478	28.043	36.614	4.451.499	5.812.082
			12.599	16.450	21.478	2.611.292	3.409.423
			7.391	9.650	12.599	1.531.809	2.000.000
			4.336	5.661	7.391	898.574	1.173.219
			2.543	3.321	4.336	527.112	688.222
			1.492	1.948	2.543	309.209	403.717
			875	1.143	1.492	181.385	236.824
				670	875	106.402	138.923
					513	62.417	81.494
						36.614	47.805
						21.478	28.043
						12.599	16.450
						7.391	9.650
						4.336	5.661
						2.543	3.321
						1.492	1.948
						875	1.143
						513	670
						301	393
						177	231
						104	135
						61	79
						36	47
						21	27
						12	16
						7	9
						4	6
							3

Table A.21. – Binomial lattice for the probabilities associated with each node for a low-cost airport.

[illegible]

[illegible]

Table A.23. – Binomial lattice for the total investment need for a low-cost airport. All prices in euros (€).

[illegible]

[illegible]

Table A.25. – Binomial lattice for the anticipation of the partial investment by 2 years for a low-cost airport.
All prices in euros (€).

[illegible]

Table A.26. – Binomial lattice for the expected cash flows for a low-cost airport. All prices in euros (€).

Year 0	Year 1	Year 2	Year 29	Year 30	Year 31	Year 49	Year 50
-287.330.000	6.240.988	-65.360.480	119.500.000	119.500.000	119.500.000	119.500.000	119.500.000
	3.661.023	4.780.000	119.500.000	119.500.000	119.500.000	119.500.000	119.500.000
		2.803.994	119.500.000	119.500.000	119.500.000	119.500.000	119.500.000
			119.500.000	119.500.000	119.500.000	119.500.000	119.500.000
			119.500.000	119.500.000	119.500.000	119.500.000	119.500.000
			119.500.000	119.500.000	119.500.000	119.500.000	119.500.000
			119.500.000	119.500.000	119.500.000	119.500.000	119.500.000
			119.500.000	119.500.000	119.500.000	119.500.000	119.500.000
			89.847.834	117.309.462	119.500.000	119.500.000	119.500.000
			-28.293.401	-128.386.147	89.847.834	119.500.000	119.500.000
			-74.263.391	-252.491.549	-28.293.401	119.500.000	119.500.000
			18.136.565	-68.340.067	-74.263.391	119.500.000	119.500.000
			10.639.083	-67.108.125	18.136.565	119.500.000	119.500.000
			6.240.988	-65.360.480	10.639.083	119.500.000	119.500.000
			3.661.023	4.780.000	6.240.988	119.500.000	119.500.000
			2.147.591	2.803.994	3.661.023	119.500.000	119.500.000
			1.259.798	1.644.850	2.147.591	119.500.000	119.500.000
			739.009	964.884	1.259.798	119.500.000	119.500.000
			433.510	566.010	739.009	89.847.834	117.309.462
			254.301	332.027	433.510	52.705.599	68.814.853
			149.175	194.770	254.301	30.917.609	40.367.451
			87.508	114.254	149.175	18.136.565	23.679.933
			51.333	67.023	87.508	10.639.083	13.890.875
			30.112	39.316	51.333	6.240.988	8.148.520
			17.664	23.063	30.112	3.661.023	4.780.000
			10.362	13.529	17.664	2.147.591	2.803.994
			6.078	7.936	10.362	1.259.798	1.644.850
			3.566	4.656	6.078	739.009	964.884
			2.092	2.731	3.566	433.510	566.010
				1.602	2.092	254.301	332.027
					1.227	149.175	194.770
						87.508	114.254
						51.333	67.023
						30.112	39.316
						17.664	23.063
						10.362	13.529
						6.078	7.936
						3.566	4.656
						2.092	2.731
						1.227	1.602
						720	940
						422	551
						248	323
						145	190
						85	111
						50	65
						29	38
						17	22
						10	13
							8

Table A.27. – Binomial lattice for the probability weighted expected cash flows for a low-cost airport.
All prices in euros (€).

[illegible]

Table A.28. – Flexible scenario free cash flows results for a low-cost airport.
All prices in euros (€).

	Year 0	Year 1	Year 2	Year 29	Year 30	Year 31	Year 49	Year 50
CF (1)	-287.330.000	6.055.144	-55.629.783	119.493.328	119.491.956	119.498.073	119.500.000	119.500.000
Discount Factor	1,0000	0,9210	0,8482	0,0919	0,0847	0,0780	0,0177	0,0163
PV CF (2)	-287.330.000	5.576.756	-47.186.916	10.984.999	10.117.010	9.318.189	2.118.198	1.950.849

(1) Cash Flows

(2) Present Value Cash Flows

Table A.29. – Flexible scenario capital cash flows results for a low-cost airport.
All prices in euros (€).

	Year 0	Year 1	Year 2	Year 29	Year 30	Year 31	Year 49	Year 50
Revenue taxes	0	1.665.165	0	32.860.665	32.860.288	32.861.970	32.862.500	32.862.500
CF (1)	-287.330.000	4.389.980	-55.629.783	86.632.663	86.631.668	86.636.103	86.637.500	86.637.500
Discount Factor	1,0000	0,9220	0,8500	0,0948	0,0874	0,0806	0,0187	0,0172
PV CF (2)	-287.330.000	4.047.480	-47.288.087	8.215.334	7.574.299	6.983.720	1.618.428	1.492.160

(1) Cash Flows after taxes

(2) Present Value Cash Flows

Table A.30. – Binomial lattice for the abandonment option for a low-cost airport.

[illegible]

Table A.31. – Flexible scenario free cash flows results for the abandonment option for a low-cost airport.
All prices in euros (€).

	Year 0	Year 1	Year 2	Year 29	Year 30	Year 31	Year 49	Year 50
CF (1)	-287.330.000	6.055.144	-55.629.783	119.493.328	119.491.956	119.498.073	119.500.000	119.500.000
Discount Factor	1,0000	0,9210	0,8482	0,0919	0,0847	0,0780	0,0177	0,0163
PV CF (2)	-287.330.000	5.576.756	-47.186.916	10.984.999	10.117.010	9.318.189	2.118.198	1.950.849

(1) Cash Flows

(2) Present Value Cash Flows

Table A.32. – Flexible scenario capital cash flows results for the abandonment option for a low-cost airport.
All prices in euros (€).

	Year 0	Year 1	Year 2	Year 29	Year 30	Year 31	Year 49	Year 50
Revenue taxes	0	1.665.165	0	32.860.665	32.860.288	32.861.970	32.862.500	32.862.500
CF (1)	-287.330.000	4.389.980	-55.629.783	86.632.663	86.631.668	86.636.103	86.637.500	86.637.500
Discount Factor	1,0000	0,9220	0,8500	0,0948	0,0874	0,0806	0,0187	0,0172
PV CF (2)	-287.330.000	4.047.480	-47.288.087	8.215.334	7.574.299	6.983.720	1.618.428	1.492.160

(1) Cash Flows after taxes

(2) Present Value Cash Flows

A.8. SENSITIVITY ANALYSIS COMPLETE RESULTS

Table A.33. – Sensitivity analysis variables and respective variations.

Variable	Base Case Scenario	Base Case -15%	Base Case +15%	Variation
Total cost (full service)	2.074.730.000 €	1.763.520.500 €	2.385.939.500 €	35,29%
Total cost (low-cost)	1.214.878.000 €	1.032.646.300 €	1.397.109.700 €	35,29%
Starting demand (Mpax)	2.000.000	1.700.000	2.300.000	35,29%
Average annual growth rate (full service)	8,11%	6,89%	9,33%	35,29%
Average annual growth rate (low-cost)	22,83%	19,41%	26,25%	35,29%
Volatility (full service)	4,38%	3,72%	5,04%	35,29%
Volatility (low-cost)	7,11%	6,04%	8,18%	35,29%
Inflows (full service)	11,07 €	9,41 €	12,73 €	35,29%
Inflows (low-cost)	9,56 €	8,13 €	10,99 €	35,29%
Out\ Inflows (full service)	65,00%	55,25%	74,75%	35,29%
Out\ Inflows (low-cost)	75,00%	63,75%	86,25%	35,29%
Risk-free return rate	4,642%	3,95%	5,34%	35,29%
Asset beta	0,5877	0,499545	0,675855	35,29%
Market risk premium	6,50%	5,53%	7,48%	35,29%
Spread	2,00%	1,70%	2,30%	35,29%
Financial leverage	67,00%	56,95%	77,05%	35,29%
Corporate tax	27,50%	23,38%	31,63%	35,29%

Table A.34. – Sensitivity analysis for a full service airport, inflexible scenario, FCF model.

Variable	Full Service Airport, Inflexible, FCF model				
	Base Case Scenario	Base Case -15%	Base Case +15%	Variation	Sensitivity
Total cost (full service)	-1.736.264.563 €	-1.425.055.063 €	-2.047.474.063 €	-35,85%	1,02
Starting demand (Mpax)	-1.736.264.563 €	-1.781.759.287 €	-1.692.661.764 €	5,13%	0,15
Average annual growth rate (full service)	-1.736.264.563 €	-1.801.007.777 €	-1.669.397.061 €	7,58%	0,21
Inflows (full service)	-1.736.264.563 €	-1.787.019.091 €	-1.685.510.036 €	5,85%	0,17
Out\ Inflows (full service)	-1.736.264.563 €	-1.641.977.763 €	-1.830.551.364 €	-10,86%	0,31
Risk-free return rate	-1.736.264.563 €	-1.692.281.219 €	-1.773.684.874 €	-4,69%	0,13
Asset beta	-1.736.264.563 €	-1.691.558.490 €	-1.773.902.895 €	-4,74%	0,13
Market risk premium	-1.736.264.563 €	-1.691.808.306 €	-1.774.079.996 €	-4,74%	0,13
Spread	-1.736.264.563 €	-1.725.621.875 €	-1.746.451.684 €	-1,20%	0,03
Financial leverage	-1.736.264.563 €	-1.735.015.921 €	-1.737.506.689 €	-0,14%	0,00
Corporate tax	-1.736.264.563 €	-1.749.010.409 €	-1.722.763.865 €	1,51%	0,04

Table A.35. – Sensitivity analysis for a full service airport, inflexible scenario, CCF model.

Variable	Full Service Airport, Inflexible, CCF model				
	Base Case Scenario	Base Case -15%	Base Case +15%	Variation	Sensitivity
Total cost (full service)	-1.810.535.672 €	-1.499.326.172 €	-2.121.745.172 €	-34,38%	0,97
Starting demand (Mpax)	-1.810.535.672 €	-1.846.147.494 €	-1.776.357.612 €	3,85%	0,11
Average annual growth rate (full service)	-1.810.535.672 €	-1.859.285.092 €	-1.760.332.656 €	5,47%	0,15
Inflows (full service)	-1.810.535.672 €	-1.850.152.888 €	-1.770.918.455 €	4,38%	0,12
Out\ Inflows (full service)	-1.810.535.672 €	-1.736.938.680 €	-1.884.132.663 €	-8,13%	0,23
Risk-free return rate	-1.810.535.672 €	-1.769.000.396 €	-1.844.532.805 €	-4,17%	0,12
Asset beta	-1.810.535.672 €	-1.776.784.354 €	-1.838.946.649 €	-3,43%	0,10
Market risk premium	-1.810.535.672 €	-1.776.972.975 €	-1.839.080.325 €	-3,43%	0,10
Corporate tax	-1.810.535.672 €	-1.798.142.648 €	-1.822.958.776 €	-1,37%	0,04

Table A.36. – Sensitivity analysis for a low-cost airport, inflexible scenario, FCF model.

Variable	Low-cost Airport, Inflexible, FCF model				
	Base Case Scenario	Base Case -15%	Base Case +15%	Variation	Sensitivity
Total cost (low-cost)	-606.743.687 €	-424.511.987 €	-788.975.387 €	-60,07%	1,70
Starting demand (Mpax)	-606.743.687 €	-643.376.784 €	-573.090.332 €	11,58%	0,33
Average annual growth rate (low-cost)	-606.743.687 €	-677.041.566 €	-546.606.931 €	21,50%	0,61
Inflows (low-cost)	-606.743.687 €	-697.709.384 €	-515.777.989 €	29,98%	0,85
Out\ Inflows (low-cost)	-606.743.687 €	-333.083.246 €	-880.404.128 €	-90,21%	2,56
Risk-free return rate	-606.743.687 €	-539.673.433 €	-665.734.276 €	-20,78%	0,59
Asset beta	-606.743.687 €	-538.589.514 €	-666.083.832 €	-21,01%	0,60
Market risk premium	-606.743.687 €	-538.964.116 €	-666.367.833 €	-21,00%	0,59
Spread	-606.743.687 €	-590.305.544 €	-622.613.175 €	-5,32%	0,15
Financial leverage	-606.743.687 €	-604.807.761 €	-608.671.477 €	-0,64%	0,02

Table A.37. – Sensitivity analysis for a low-cost airport, inflexible scenario, CCF model.

Variable	Low-cost Airport, Inflexible, CCF model				
	Base Case Scenario	Base Case -15%	Base Case +15%	Variation	Sensitivity
Total cost (low-cost)	-753.502.770 €	-571.271.070 €	-935.734.470 €	-48,37%	1,37
Starting demand (Mpax)	-753.502.770 €	-782.011.451 €	-727.191.599 €	7,28%	0,21
Average annual growth rate (low-cost)	-753.502.770 €	-806.009.812 €	-708.463.267 €	12,95%	0,37
Inflows (low-cost)	-753.502.770 €	-867.168.966 €	-684.489.530 €	24,24%	0,69
Out\ Inflows (low-cost)	-753.502.770 €	-545.883.917 €	-961.121.624 €	-55,11%	1,56
Risk-free return rate	-753.502.770 €	-690.960.057 €	-806.808.519 €	-15,37%	0,44
Asset beta	-753.502.770 €	-702.490.888 €	-797.900.204 €	-12,66%	0,36
Market risk premium	-753.502.770 €	-702.771.327 €	-798.112.651 €	-12,65%	0,36
Corporate tax	-753.502.770 €	-729.558.689 €	-777.504.969 €	-6,36%	0,18

Table A.38. – Sensitivity analysis for a full service airport, flexible scenario, FCF model.

Variable	Full Service Airport, Flexible, FCF model				
	Base Case Scenario	Base Case -15%	Base Case +15%	Variation	Sensitivity
Total cost (full service)	-873.880.395 €	-683.292.897 €	-1.064.467.894 €	-43,62%	1,24
Starting demand (Mpax)	-873.880.395 €	-866.428.675 €	-906.364.056 €	-4,57%	0,13
Average annual growth rate (full service)	-873.880.395 €	-882.384.697 €	-852.681.738 €	3,40%	0,10
Volatility (full service)	-873.880.395 €	-844.864.837 €	-930.839.815 €	-9,84%	0,28
Inflows (full service)	-873.880.395 €	-933.367.917 €	-814.392.874 €	13,61%	0,39
Out\ Inflows (full service)	-873.880.395 €	-763.370.294 €	-984.390.497 €	-25,29%	0,72
Risk-free return rate	-873.880.395 €	-871.595.455 €	-874.447.693 €	-0,33%	0,01
Asset beta	-873.880.395	-871.544.922	-874.446.819	-0,33%	0,01
Market risk premium	-873.880.395	-871.562.434	-874.446.072	-0,33%	0,01
Spread	-873.880.395	-873.476.891	-874.170.250	-0,08%	0,00
Financial leverage	-873.880.395	-873.838.924	-873.920.871	-0,01%	0,00
Corporate tax	-873.880.395	-874.227.726	-873.351.597	0,10%	0,00

Table A.39. – Sensitivity analysis for a full service airport, flexible scenario, CCF model.

Variable	Full Service Airport, Flexible, CCF model				
	Base Case Scenario	Base Case -15%	Base Case +15%	Variation	Sensitivity
Total cost (full service)	-909.035.323	-721.244.219	-1.097.909.527	-41,44%	1,17
Starting demand (Mpax)	-909.035.323	-896.956.085	-943.125.091	-5,08%	0,14
Average annual growth rate (full service)	-909.035.323	-909.980.080	-898.392.798	1,27%	0,04
Volatility (full service)	-909.035.323	-881.366.003	-963.280.643	-9,01%	0,26
Inflows (full service)	-909.035.323	-961.572.602	-857.543.152	11,44%	0,32
Out\ Inflows (full service)	-909.035.323	-813.992.808	-1.007.253.379	-21,26%	0,60
Risk-free return rate	-909.035.323	-911.513.514	-905.098.203	0,71%	0,02
Asset beta	-909.035.323	-911.220.392	-905.880.356	0,59%	0,02
Market risk premium	-909.035.323	-911.212.367	-905.862.299	0,59%	0,02
Corporate tax	-909.035.323	-903.721.710	-914.361.834	-1,17%	0,03

Table A.40. – Sensitivity analysis for a low-cost airport, flexible scenario, FCF model.

Variable	Low-cost Airport, Flexible, FCF model				
	Base Case Scenario	Base Case -15%	Base Case +15%	Variation	Sensitivity
Total cost (low-cost)	-169.990.641 €	-45.903.893 €	-294.077.389 €	-145,99%	4,14
Starting demand (Mpax)	-169.990.641 €	-183.744.794 €	-178.452.536 €	3,11%	0,09
Average annual growth rate (low-cost)	-169.990.641 €	-261.865.780 €	-83.058.468 €	105,19%	2,98
Volatility (low-cost)	-169.990.641 €	-128.054.718 €	-217.960.888 €	-52,89%	1,50
Inflows (low-cost)	-169.990.641 €	-268.303.791 €	-71.677.491 €	115,67%	3,28
Out\ Inflows (low-cost)	-169.990.641 €	125.773.814 €	-465.755.097 €	-347,98%	9,86
Risk-free return rate	-169.990.641 €	-123.324.322 €	-209.482.348 €	-50,68%	1,44
Asset beta	-169.990.641 €	-122.556.476 €	-209.711.466 €	-51,27%	1,45
Market risk premium	-169.990.641 €	-122.821.890 €	-209.897.571 €	-51,22%	1,45
Spread	-169.990.641 €	-158.714.702 €	-180.769.088 €	-12,97%	0,37
Financial leverage	-169.990.641 €	-168.668.452 €	-171.305.713 €	-1,55%	0,04
Corporate tax	-169.990.641 €	-183.473.639 €	-155.684.404 €	16,35%	0,46

Table A.41. – Sensitivity analysis for a low-cost airport, flexible scenario, CCF model.

Variable	Low-cost Airport, Flexible, CCF model				
	Base Case Scenario	Base Case -15%	Base Case +15%	Variation	Sensitivity
Total cost (low-cost)	-293.007.681 €	-170.503.541 €	-415.511.822 €	-83,62%	2,37
Starting demand (Mpax)	-293.007.681 €	-293.906.370 €	-306.055.295 €	-4,15%	0,12
Average annual growth rate (low-cost)	-293.007.681 €	-356.370.175 €	-237.817.008 €	40,46%	1,15
Volatility (low-cost)	-293.007.681 €	-254.102.974 €	-333.232.408 €	-27,01%	0,77
Inflows (low-cost)	-293.007.681 €	-371.341.554 €	-214.673.809 €	53,47%	1,51
Out\ Inflows (low-cost)	-293.007.681 €	-57.348.718 €	-529.851.641 €	-161,26%	4,57
Risk-free return rate	-293.007.681 €	-253.614.833 €	-324.423.275 €	-24,17%	0,68
Asset beta	-293.007.681 €	-261.057.378 €	-319.332.038 €	-19,89%	0,56
Market risk premium	-293.007.681 €	-261.237.435 €	-319.454.244 €	-19,87%	0,56
Corporate tax	-293.007.681 €	-273.236.478 €	-312.826.873 €	-13,51%	0,38

A.9. MONTE CARLO SIMULATIONS COMPLETE RESULTS

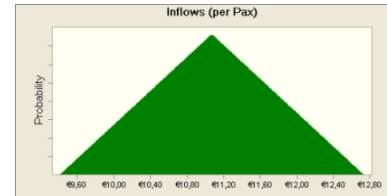
A.9.1. ASSUMPTIONS

A.9.1.1. Full Service Airport

Assumption: Inflows (per Pax)

Triangular distribution with parameters:

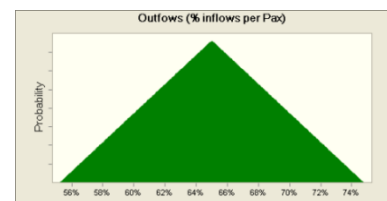
Minimum	€9,41
Likeliest	€11,07
Maximum	€12,73



Assumption: Outflows (% inflows per Pax)

Triangular distribution with parameters:

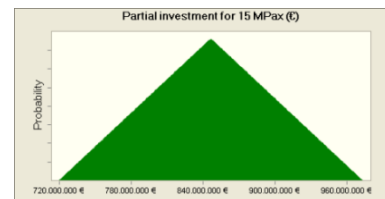
Minimum	55%
Likeliest	65%
Maximum	75%



Assumption: Partial investment for 15 MPax (€)

Triangular distribution with parameters:

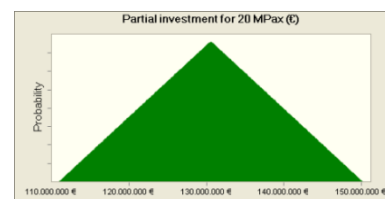
Minimum	719.414.500 €
Likeliest	846.370.000 €
Maximum	973.325.500 €



Assumption: Partial investment for 20 MPax (€)

Triangular distribution with parameters:

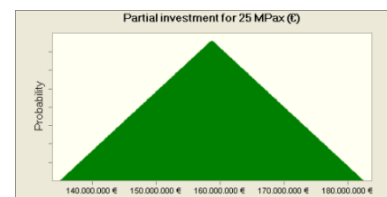
Minimum	110.959.000 €
Likeliest	130.540.000 €
Maximum	150.121.000 €



Assumption: Partial investment for 25 MPax (€)

Triangular distribution with parameters:

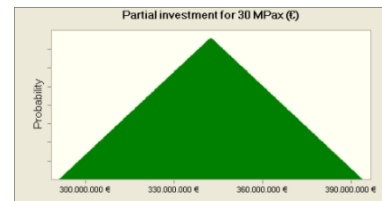
Minimum	134.878.850 €
Likeliest	158.681.000 €
Maximum	182.483.150 €



Assumption: Partial investment for 30 MPax (€)

Triangular distribution with parameters:

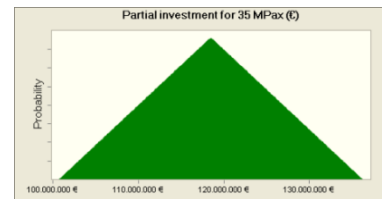
Minimum	291.040.000 €
Likeliest	342.400.000 €
Maximum	393.760.000 €



Assumption: Partial investment for 35 MPax (€)

Triangular distribution with parameters:

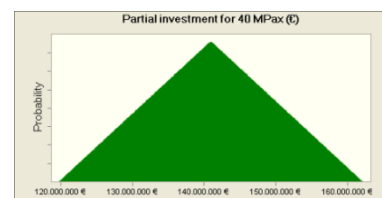
Minimum	100.681.650 €
Likeliest	118.449.000 €
Maximum	136.216.350 €



Assumption: Partial investment for 40 MPax (€)

Triangular distribution with parameters:

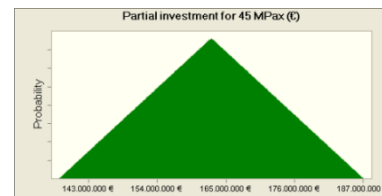
Minimum	119.781.150 €
Likeliest	140.919.000 €
Maximum	162.056.850 €



Assumption: Partial investment for 45 MPax (€)

Triangular distribution with parameters:

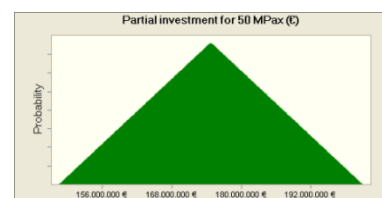
Minimum	138.244.000 €
Likeliest	162.640.000 €
Maximum	187.036.000 €



Assumption: Partial investment for 50 MPax (€)

Triangular distribution with parameters:

Minimum	148.521.350 €
Likeliest	174.731.000 €
Maximum	200.940.650 €

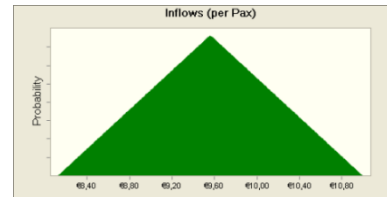


A.9.1.2. Low-Cost Airport

Assumption: Inflows (per Pax)

Triangular distribution with parameters:

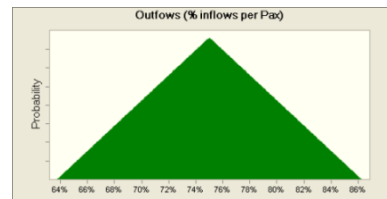
Minimum	€8,13
Likeliest	€9,56
Maximum	€10,99



Assumption: Outflows (% inflows per Pax)

Triangular distribution with parameters:

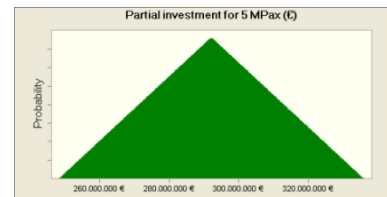
Minimum	64%
Likeliest	75%
Maximum	86%



Assumption: Partial investment for 5 MPax (€)

Triangular distribution with parameters:

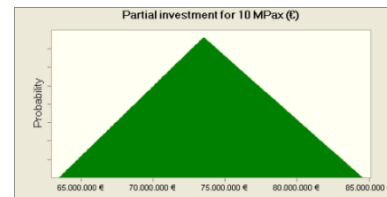
Minimum	248.293.500 €
Likeliest	292.110.000 €
Maximum	335.926.500 €



Assumption: Partial investment for 10 MPax (€)

Triangular distribution with parameters:

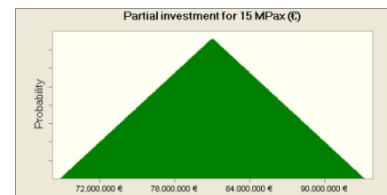
Minimum	63.482.650 €
Likeliest	73.509.000 €
Maximum	84.535.350 €



Assumption: Partial investment for 15 MPax (€)

Triangular distribution with parameters:

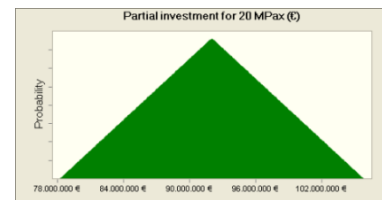
Minimum	68.849.150 €
Likeliest	80.999.000 €
Maximum	93.148.850 €



Assumption: Partial investment for 20 MPax (€)

Triangular distribution with parameters:

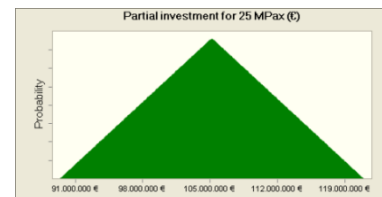
Minimum	78.217.000 €
Likeliest	92.020.000 €
Maximum	105.823.000 €



Assumption: Partial investment for 25 MPax (€)

Triangular distribution with parameters:

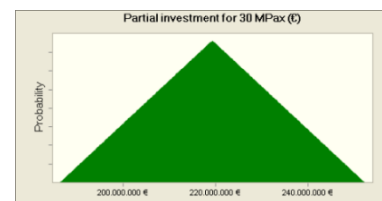
Minimum	89.403.850 €
Likeliest	105.181.000 €
Maximum	120.958.150 €



Assumption: Partial investment for 30 MPax (€)

Triangular distribution with parameters:

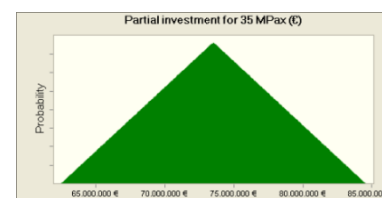
Minimum	186.447.500 €
Likeliest	219.350.000 €
Maximum	252.252.500 €



Assumption: Partial investment for 35 MPax (€)

Triangular distribution with parameters:

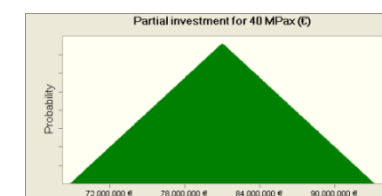
Minimum	62.482.650 €
Likeliest	73.509.000 €
Maximum	84.535.350 €



Assumption: Partial investment for 40 MPax (€)

Triangular distribution with parameters:

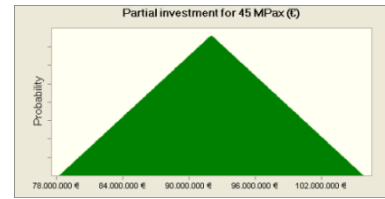
Minimum	68.849.150 €
Likeliest	80.999.000 €
Maximum	93.148.850 €



Assumption: Partial investment for 45 MPax (€)

Triangular distribution with parameters:

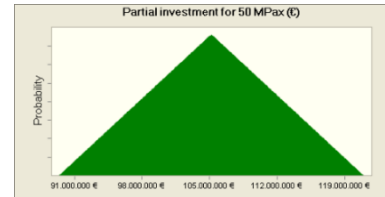
Minimum	78.217.000 €
Likeliest	92.020.000 €
Maximum	105.823.000 €



Assumption: Partial investment for 50 MPax (€)

Triangular distribution with parameters:

Minimum	89.403.850 €
Likeliest	105.181.000 €
Maximum	120.958.150 €



Assumption: Risk-Free Return Rate

Triangular distribution with parameters:

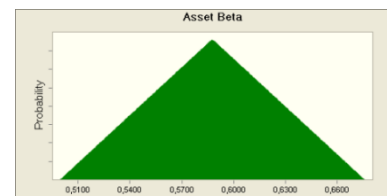
Minimum	3,946%
Likeliest	4,642%
Maximum	5,338%



Assumption: Asset Beta

Triangular distribution with parameters:

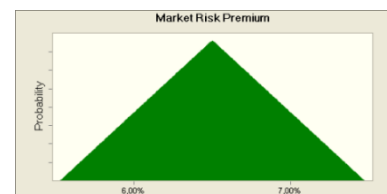
Minimum	0,4995
Likeliest	0,5877
Maximum	0,6759



Assumption: Market Risk Premium

Triangular distribution with parameters:

Minimum	5,53%
Likeliest	6,50%
Maximum	7,48%



A.9.2. RESULTS

A.9.2.1. Full Service Airport

Figure A.1. – Monte Carlo simulation results for a full service airport, inflexible scenario, FCF model.

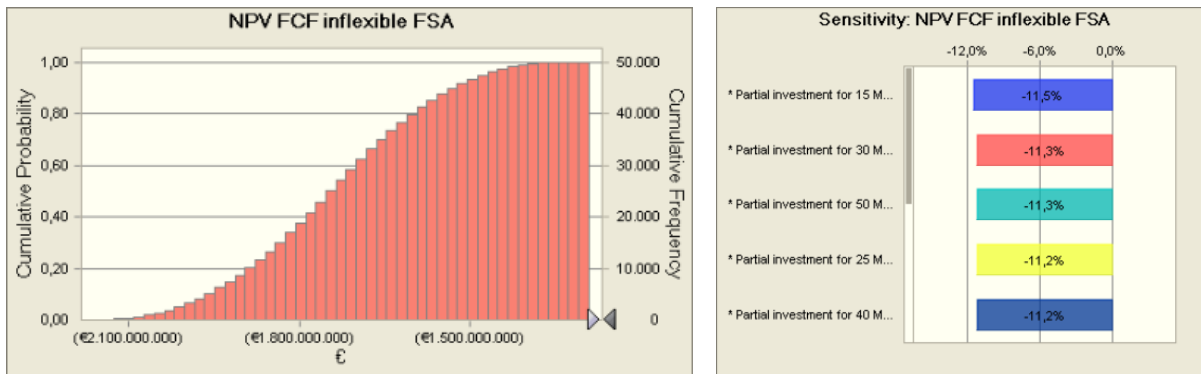


Table A.42. – Monte Carlo simulation results for a full service airport, inflexible scenario, FCF model.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	- 1.222.243.996,66 €
Mean	- 1.735.887.599 €	10%	- 1.061.210.054,28 €
Median	- 1.736.506.061 €	20%	- 1.010.582.568,23 €
Standard Deviation	160.118.279 €	30%	- 972.409.094,06 €
Skewness	0,0081	40%	- 939.633.235,57 €
Kurtosis	2,44	50%	- 909.542.449,22 €
Coefficient of Variability	-0,0922	60%	- 879.278.361,19 €
Minimum	- 2.162.120.834,84 €	70%	- 845.911.701,50 €
Maximum	- 1.291.761.784,70 €	80%	- 807.766.799,11 €
Range Width	870.359.050,15 €	90%	- 758.692.694,51 €
Mean Std. Error	716.070,71 €	100%	- 588.342.371,02 €

Figure A.2. – Monte Carlo simulation results for a full service airport, inflexible scenario, CCF model.

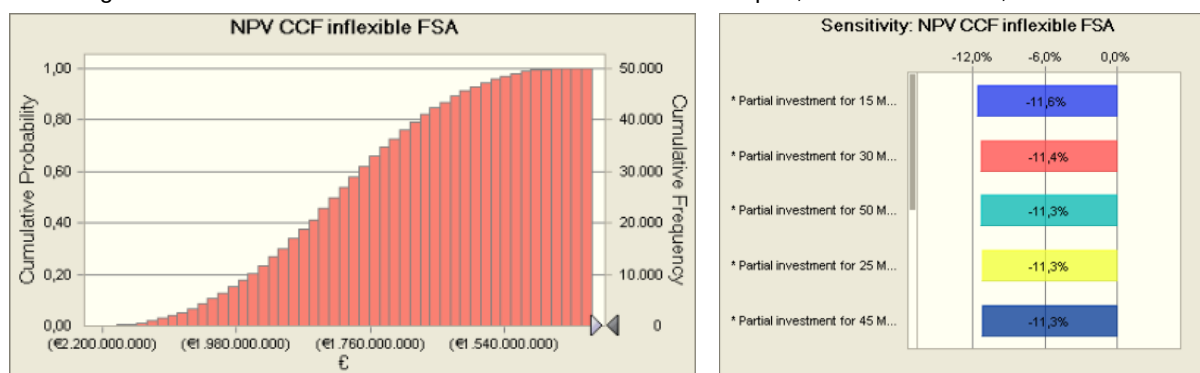


Table A.43. – Monte Carlo simulation results for a full service airport, inflexible scenario, CCF model.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	- 2.210.031.268 €
Mean	- 1.810.174.749 €	10%	- 2.014.725.569 €
Median	- 1.810.626.133 €	20%	- 1.946.654.218 €
Standard Deviation	152.057.905 €	30%	- 1.895.085.797 €
Skewness	0,0044	40%	- 1.850.495.033 €
Kurtosis	2,43	50%	- 1.810.630.028 €
Coefficient of Variability	-0,0840	60%	- 1.769.640.165 €
Minimum	- 2.210.031.268 €	70%	- 1.725.355.202 €
Maximum	- 1.396.502.010 €	80%	- 1.673.541.810 €
Range Width	813.529.258 €	90%	- 1.606.113.325 €
Mean Std. Error	680.024 €	100%	- 1.396.502.010 €

Figure A.3. – Monte Carlo simulation results for a full service airport, flexible scenario, FCF model.

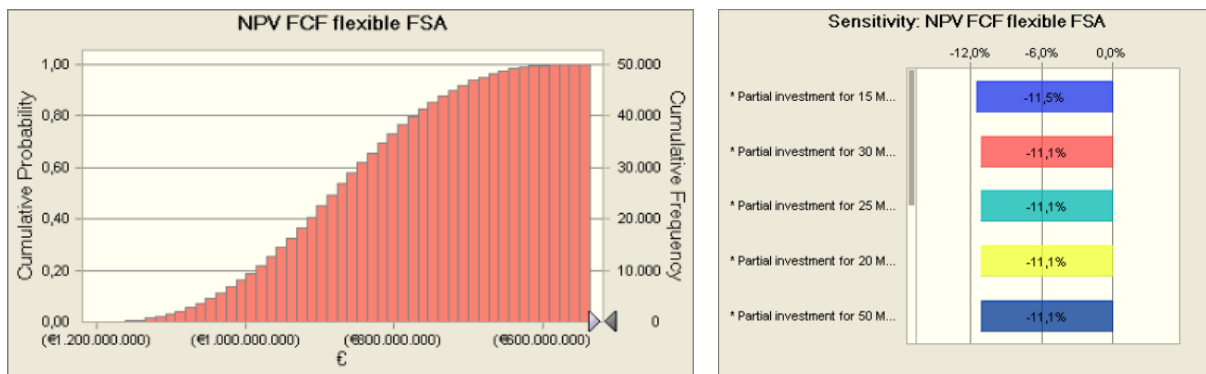


Table A.44. – Monte Carlo simulation results for a full service airport, flexible scenario, FCF model.

Statistics	Forecast values		Percentiles	Forecast values	
Trials		50.000	0%	-	1.202.288.852 €
Mean	-	873.582.604 €	10%	-	1.033.524.136 €
Median	-	874.440.462 €	20%	-	980.650.538 €
Standard Deviation		119.856.426 €	30%	-	940.601.416 €
Skewness		0,0237	40%	-	906.209.257 €
Kurtosis		2,47	50%	-	874.440.760 €
Coefficient of Variability		-0,1372	60%	-	842.287.145 €
Minimum	-	1.202.288.852 €	70%	-	806.949.145 €
Maximum	-	523.576.923 €	80%	-	766.183.202 €
Range Width		678.711.929 €	90%	-	713.709.502 €
Mean Std. Error		536.014 €	100%	-	523.576.923 €

Figure A.4. – Monte Carlo simulation results for a full service airport, flexible scenario, CCF model.

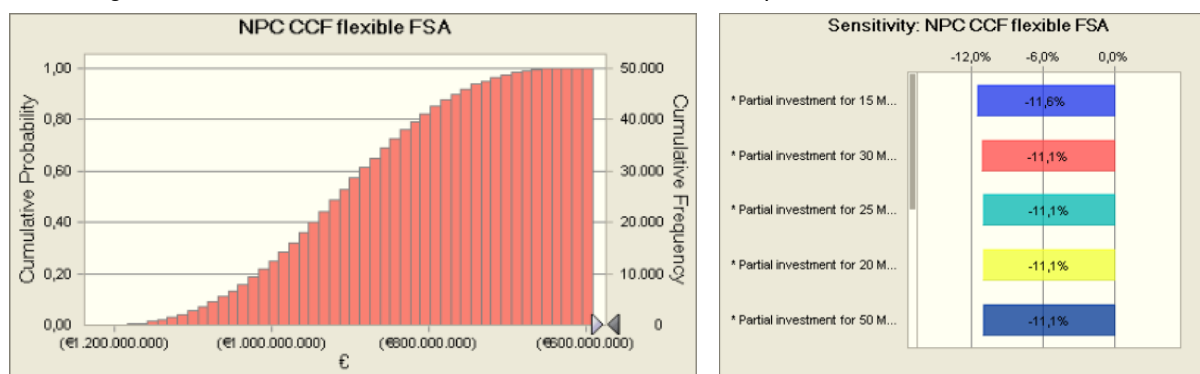


Table A.45. – Monte Carlo simulation results for a full service airport, flexible scenario, CCF model.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	- 1.202.288.852 €
Mean	- 909.444.855 €	10%	- 1.033.524.136 €
Median	- 909.539.973 €	20%	- 980.650.538 €
Standard Deviation	113.159.181 €	30%	- 940.601.416 €
Skewness	-0,0032	40%	- 906.209.257 €
Kurtosis	2,46	50%	- 874.440.760 €
Coefficient of Variability	-0,1244	60%	- 842.287.145 €
Minimum	- 1.222.243.997 €	70%	- 806.949.145 €
Maximum	- 588.342.371 €	80%	- 766.183.202 €
Range Width	633.901.626 €	90%	- 713.709.502 €
Mean Std. Error	506.063 €	100%	- 523.576.923 €

Figure A.5. – Monte Carlo simulation results for a full service airport, option value, FCF model.

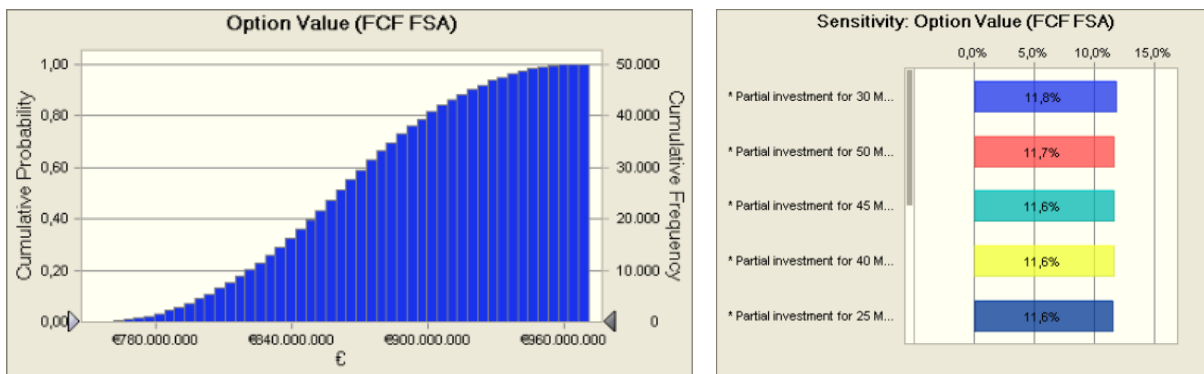


Table A.46. – Monte Carlo simulation results for a full service airport, option value, FCF model.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	752.460.019 €
Mean	862.304.995 €	10%	803.969.997 €
Median	862.168.350 €	20%	823.192.249 €
Standard Deviation	43.256.243 €	30%	838.218.287 €
Skewness	0,0031	40%	850.853.930 €
Kurtosis	2,40	50%	862.167.614 €
Coefficient of Variability	0,0502	60%	873.588.482 €
Minimum	752.460.019 €	70%	886.339.572 €
Maximum	970.426.955 €	80%	901.207.841 €
Range Width	217.966.936 €	90%	920.918.720 €
Mean Std. Error	193.448 €	100%	970.426.955 €

Figure A.6. – Monte Carlo simulation results for a full service airport, option value, CCF model.

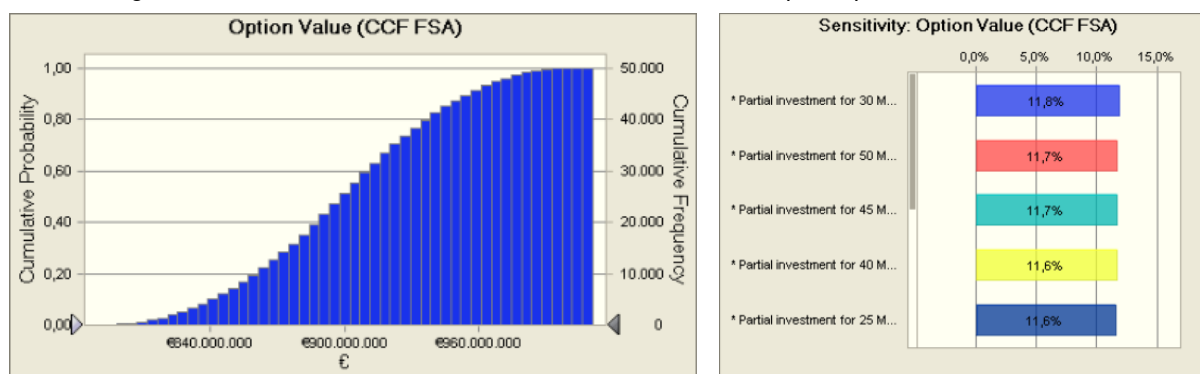


Table A.47. – Monte Carlo simulation results for a full service airport, option value, CCF model.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	789.489.333 €
Mean	900.729.894 €	10%	843.538.263 €
Median	901.065.676 €	20%	862.638.683 €
Standard Deviation	42.218.324 €	30%	877.508.507 €
Skewness	-0,0334	40%	889.872.961 €
Kurtosis	2,40	50%	901.062.734 €
Coefficient of Variability	0,0469	60%	912.183.680 €
Minimum	789.489.333 €	70%	924.371.442 €
Maximum	1.010.488.534 €	80%	938.735.560 €
Range Width	220.999.202 €	90%	957.590.231 €
Mean Std. Error	188.806 €	100%	1.010.488.534 €

A.9.2.2. Low-Cost Airport without Financial Variables

Figure A.7. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, FCF model.

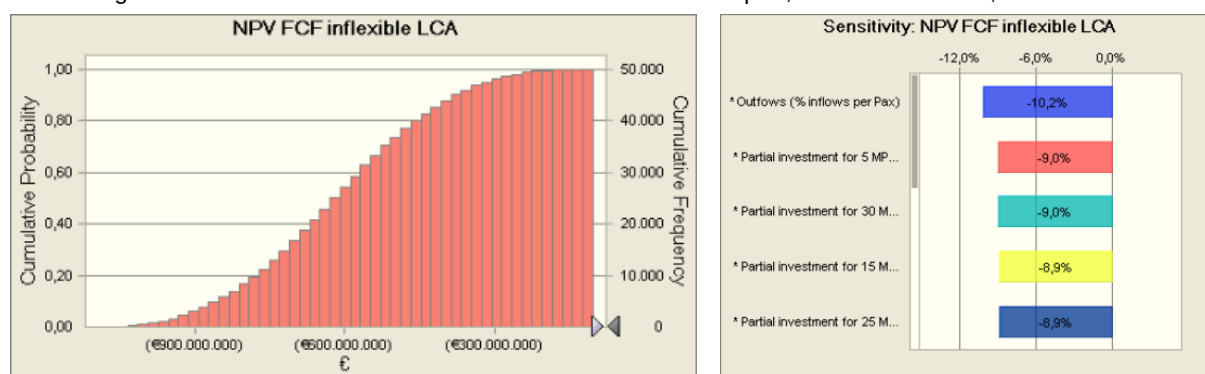


Table A.48. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, FCF model.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	- 1.095.370.850 €
Mean	- 607.667.176 €	10%	- 846.767.108 €
Median	- 609.590.442 €	20%	- 767.734.909 €
Standard Deviation	179.983.976 €	30%	- 707.645.558 €
Skewness	0,0523	40%	- 657.387.131 €
Kurtosis	2,51	50%	- 609.592.937 €
Coefficient of Variability	-0,2962	60%	- 561.861.000 €
Minimum	- 1.095.370.850 €	70%	- 510.061.482 €
Maximum	- 51.285.086 €	80%	- 447.899.118 €
Range Width	1.044.085.764 €	90%	- 366.935.548 €
Mean Std. Error	804.913 €	100%	- 51.285.086 €

Figure A.8. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, CCF model.

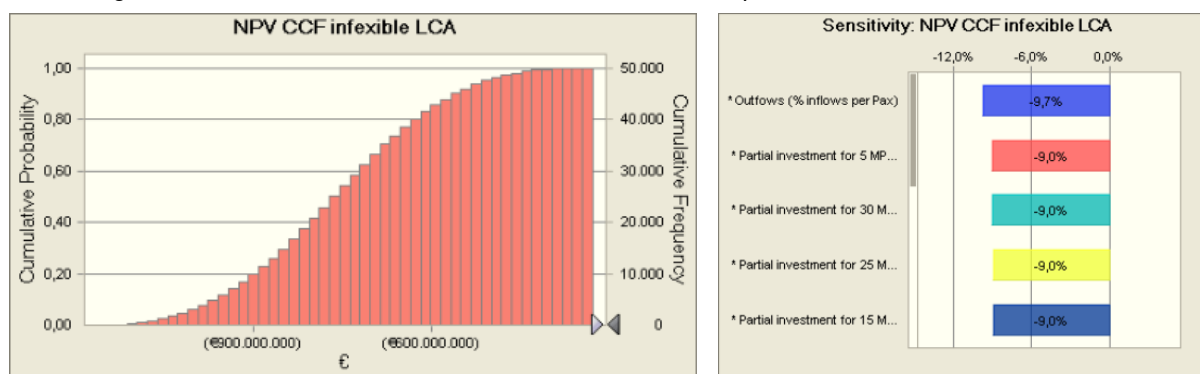


Table A.49. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, CCF model.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	- 1.166.613.164 €
Mean	- 754.234.979 €	10%	- 956.873.253 €
Median	- 755.385.306 €	20%	- 889.961.253 €
Standard Deviation	152.688.568 €	30%	- 839.109.131 €
Skewness	0,0425	40%	- 796.183.106 €
Kurtosis	2,50	50%	- 755.385.770 €
Coefficient of Variability	-0,2024	60%	- 714.796.552 €
Minimum	- 1.166.613.164 €	70%	- 671.047.102 €
Maximum	- 291.031.904 €	80%	- 618.281.976 €
Range Width	875.581.260 €	90%	- 550.368.476 €
Mean Std. Error	682.844 €	100%	- 291.031.904 €

Figure A.9. – Monte Carlo simulation results for a low-cost airport, flexible scenario, FCF model.

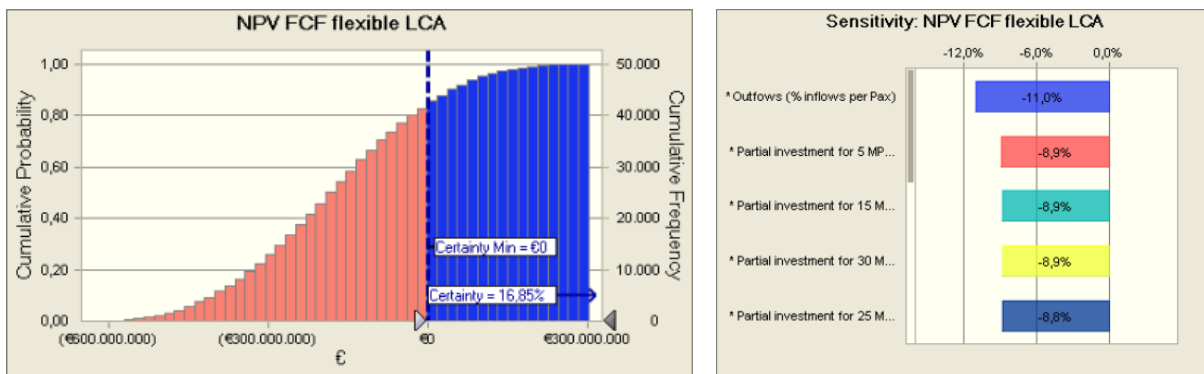


Table A.50. – Monte Carlo simulation results for a low-cost airport, flexible scenario, FCF model.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	- 627.905.498 €
Mean	- 171.022.767 €	10%	- 394.582.062 €
Median	- 173.223.838 €	20%	- 320.859.898 €
Standard Deviation	168.441.253 €	30%	- 264.683.225 €
Skewness	0,0679	40%	- 218.061.088 €
Kurtosis	2,52	50%	- 173.226.785 €
Coefficient of Variability	-0,9849	60%	- 128.475.095 €
Minimum	- 627.905.498 €	70%	- 79.935.768 €
Maximum	362.069.255 €	80%	- 21.749.390 €
Range Width	989.974.753 €	90%	53.841.423 €
Mean Std. Error	753.292 €	100%	362.069.255 €

Figure A.10. – Monte Carlo simulation results for a low-cost airport, flexible scenario, CCF model.

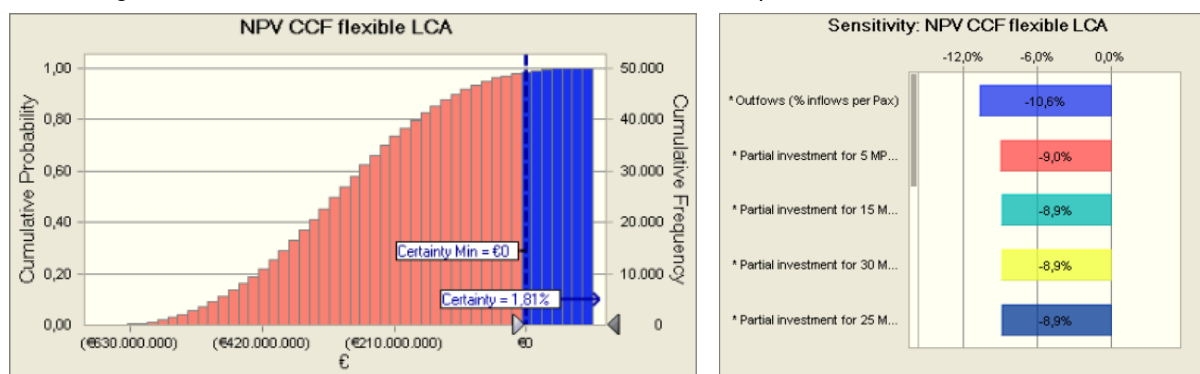


Table A.51. – Monte Carlo simulation results for a low-cost airport, flexible scenario, CCF model.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	- 684.374.247 €
Mean	- 293.953.520 €	10%	- 483.328.445 €
Median	- 295.500.720 €	20%	- 420.554.669 €
Standard Deviation	142.683.708 €	30%	- 373.070.133 €
Skewness	0,0550	40%	- 333.569.000 €
Kurtosis	2,52	50%	- 295.507.477 €
Coefficient of Variability	-0,4854	60%	- 257.626.538 €
Minimum	- 684.374.247 €	70%	- 216.926.685 €
Maximum	150.393.347 €	80%	- 167.473.942 €
Range Width	834.767.594 €	90%	- 103.715.314 €
Mean Std. Error	638.101 €	100%	150.393.347 €

Figure A.11. – Monte Carlo simulation results for a low-cost airport, option value, FCF model.

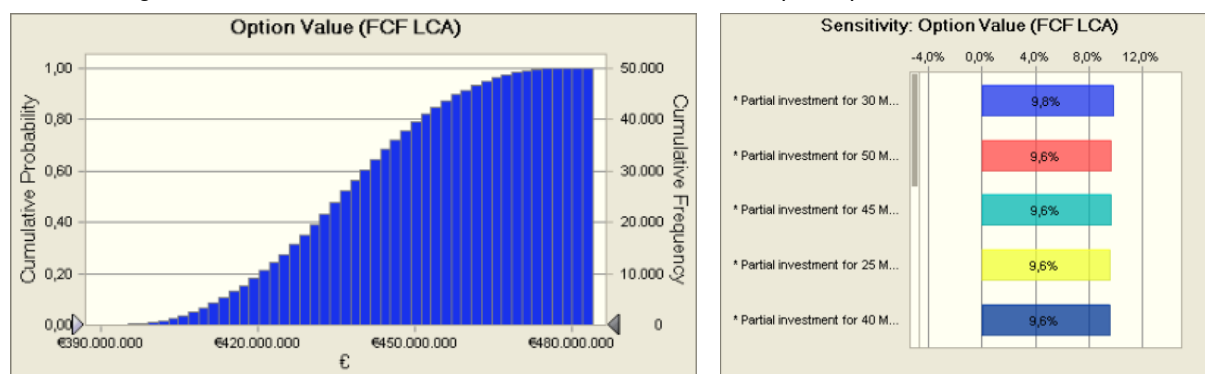


Table A.52. – Monte Carlo simulation results for a low-cost airport, option value, FCF model.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	388.362.857 €
Mean	436.644.409 €	10%	413.855.171 €
Median	436.676.311 €	20%	421.554.643 €
Standard Deviation	16.852.979 €	30%	427.381.757 €
Skewness	-0,0171	40%	432.250.950 €
Kurtosis	2,44	50%	436.676.268 €
Coefficient of Variability	0,0386	60%	441.233.519 €
Minimum	388.362.857 €	70%	446.084.766 €
Maximum	486.387.649 €	80%	451.723.613 €
Range Width	98.024.792 €	90%	459.232.183 €
Mean Std. Error	75.369 €	100%	486.387.649 €

Figure A.12. – Monte Carlo simulation results for a low-cost airport, option value, CCF model.

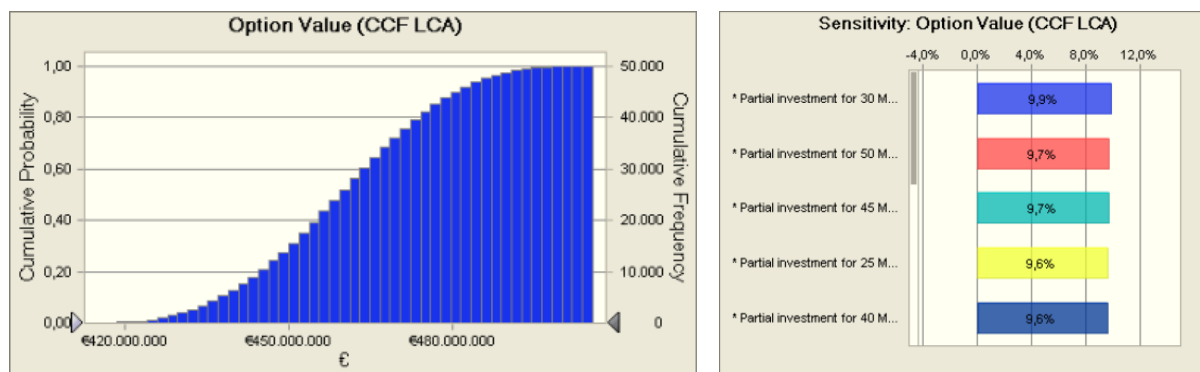


Table A.53. – Monte Carlo simulation results for a low-cost airport, option value, CCF model.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	410.543.786 €
Mean	460.281.458 €	10%	438.520.953 €
Median	460.393.211 €	20%	445.796.649 €
Standard Deviation	16.194.342 €	30%	451.393.166 €
Skewness	-0,0324	40%	456.035.875 €
Kurtosis	2,50	50%	460.392.958 €
Coefficient of Variability	0,0352	60%	464.785.495 €
Minimum	410.543.786 €	70%	469.451.259 €
Maximum	511.130.142 €	80%	474.739.368 €
Range Width	100.586.356 €	90%	481.708.671 €
Mean Std. Error	72.423 €	100%	511.130.142 €

A.9.2.3. Low-Cost Airport with Financial Variables

Figure A.13. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, FCF model, including financial variables.

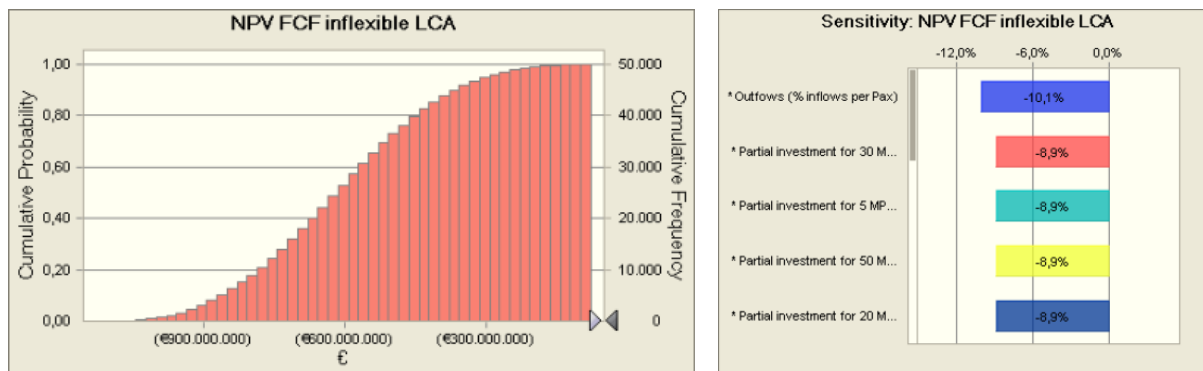


Table A.54. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, FCF model, including financial variables.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	- 1.135.629.144 €
Mean	- 604.520.340 €	10%	- 852.014.401 €
Median	- 607.139.655 €	20%	- 771.755.435 €
Standard Deviation	187.191.555 €	30%	- 709.875.844 €
Skewness	0,1040	40%	- 657.821.122 €
Kurtosis	2,56	50%	- 607.144.006 €
Coefficient of Variability	-0,3097	60%	- 557.689.506 €
Minimum	- 1.135.629.144 €	70%	- 503.471.902 €
Maximum	78.974.487 €	80%	- 439.762.893 €
Range Width	1.214.603.631 €	90%	- 355.482.964 €
Mean Std. Error	837.146 €	100%	78.974.487 €

Figure A.14. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, CCF model, including financial variables.

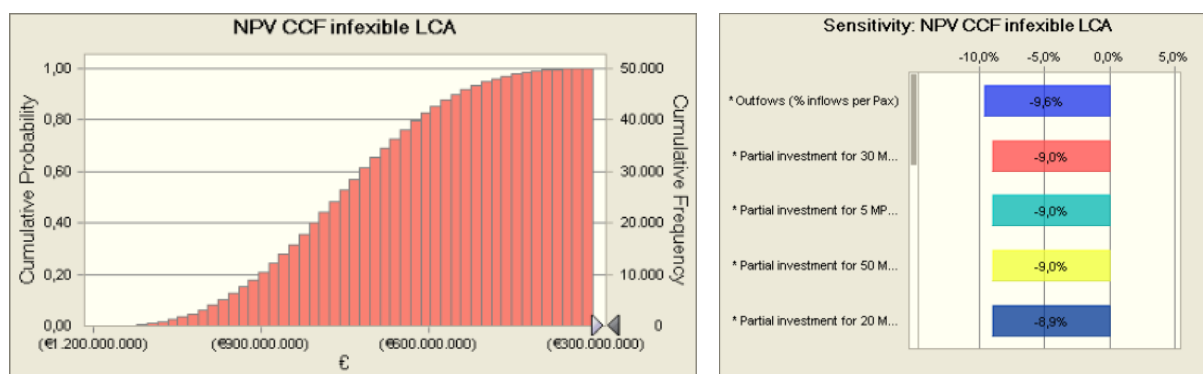


Table A.55. – Monte Carlo simulation results for a low-cost airport, inflexible scenario, CCF model, including financial variables.

Statistics	Forecast values		Percentiles	Forecast values	
Trials	50.000		0%	-	1.200.171.338 €
Mean	-	751.593.587 €	10%	-	961.046.246 €
Median	-	753.665.961 €	20%	-	893.169.079 €
Standard Deviation	158.412.943 €		30%	-	840.946.919 €
Skewness	0,0907		40%	-	796.441.075 €
Kurtosis	2,55		50%	-	753.668.366 €
Coefficient of Variability	-0,2108		60%	-	712.161.841 €
Minimum	-	1.200.171.338 €	70%	-	665.582.438 €
Maximum	-	182.352.649 €	80%	-	612.321.403 €
Range Width	1.017.818.689 €		90%	-	540.553.653 €
Mean Std. Error	708.444 €		100%	-	182.352.649 €

Figure A.15. – Monte Carlo simulation results for a low-cost airport, flexible scenario, FCF model, including financial variables.

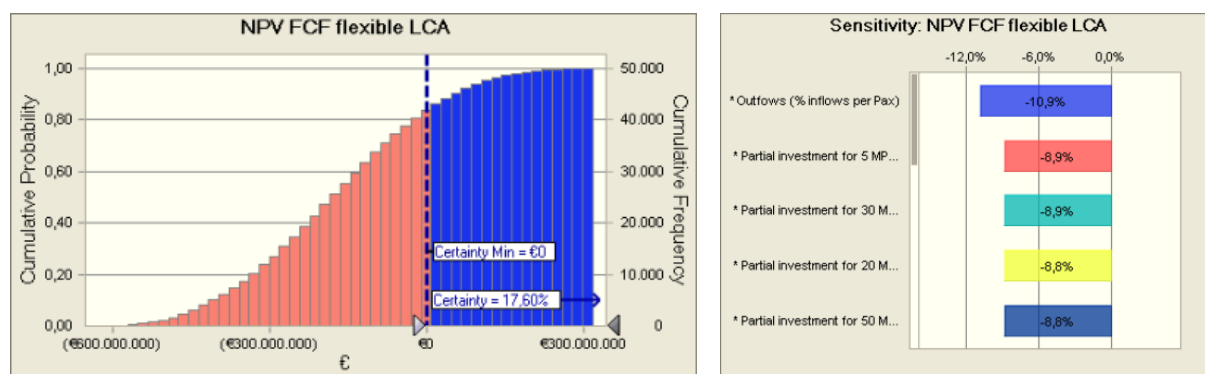


Table A.56. – Monte Carlo simulation results for a low-cost airport, flexible scenario, FCF model, including financial variables.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	- 628.842.769 €
Mean	- 168.146.645 €	10%	- 397.408.702 €
Median	- 171.078.551 €	20%	- 322.882.159 €
Standard Deviation	173.000.055 €	30%	- 265.872.430 €
Skewness	0,1133	40%	- 217.534.970 €
Kurtosis	2,56	50%	- 171.079.242 €
Coefficient of Variability	-1,0289	60%	- 124.850.731 €
Minimum	- 628.842.769 €	70%	- 75.381.958 €
Maximum	468.903.381 €	80%	- 16.034.232 €
Range Width	1.097.746.150 €	90%	62.046.445 €
Mean Std. Error	773.680 €	100%	468.903.381 €

Figure A.16. – Monte Carlo simulation results for a low-cost airport, flexible scenario, CCF model, including financial variables.

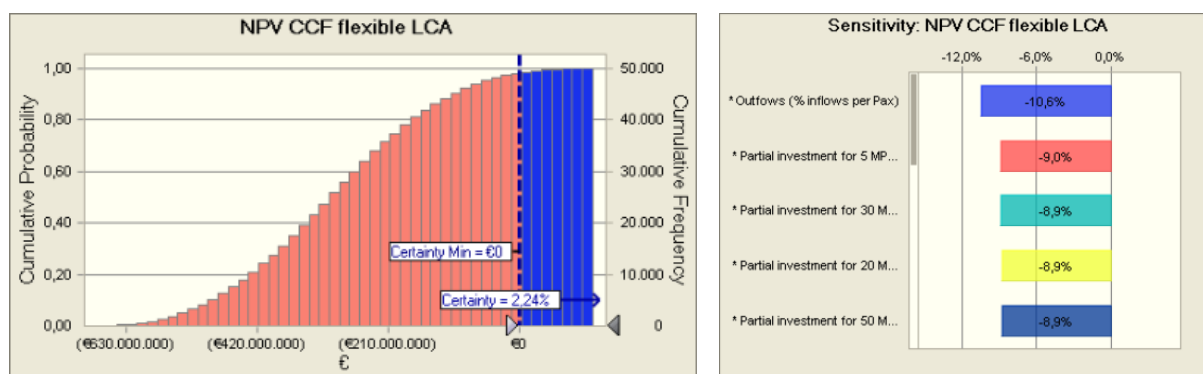


Table A.57. – Monte Carlo simulation results for a low-cost airport, flexible scenario, CCF model, including financial variables.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	- 676.548.067 €
Mean	- 291.582.017 €	10%	- 485.085.131 €
Median	- 293.568.003 €	20%	- 421.763.021 €
Standard Deviation	145.989.242 €	30%	- 373.695.494 €
Skewness	0,0945	40%	- 332.916.243 €
Kurtosis	2,55	50%	- 293.583.214 €
Coefficient of Variability	-0,5007	60%	- 254.698.448 €
Minimum	- 676.548.067 €	70%	- 212.902.186 €
Maximum	233.230.307 €	80%	- 163.202.468 €
Range Width	909.778.374 €	90%	- 97.149.441 €
Mean Std. Error	652.884 €	100%	233.230.307 €

Figure A.17. – Monte Carlo simulation results for a low-cost airport, option value, FCF model, including financial variables.

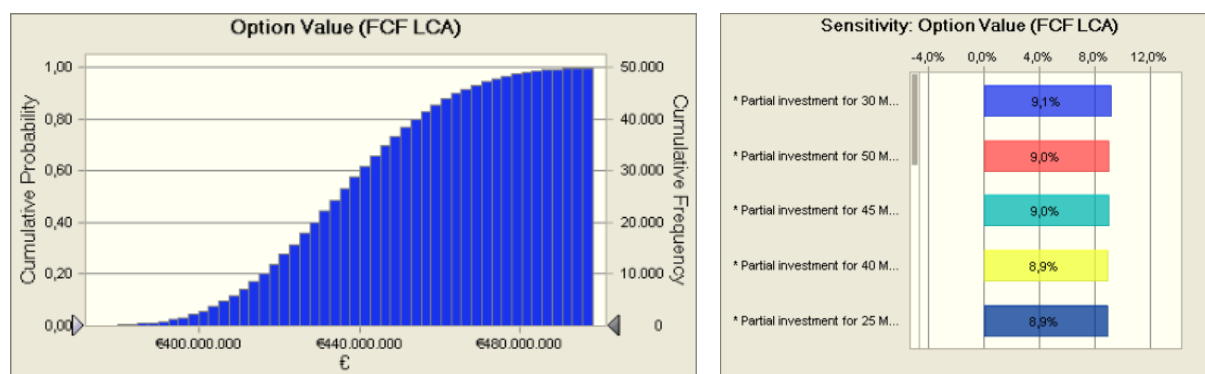


Table A.58. – Monte Carlo simulation results for a low-cost airport, option value, FCF model, including financial variables.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	356.577.468 €
Mean	436.373.695 €	10%	407.997.558 €
Median	435.876.503 €	20%	417.222.971 €
Standard Deviation	22.104.924 €	30%	424.069.062 €
Skewness	0,1276	40%	430.043.078 €
Kurtosis	2,79	50%	435.875.956 €
Coefficient of Variability	0,0507	60%	441.659.275 €
Minimum	356.577.468 €	70%	447.916.725 €
Maximum	517.943.680 €	80%	455.313.232 €
Range Width	161.366.212 €	90%	465.411.564 €
Mean Std. Error	98.856 €	100%	517.943.680 €

Figure A.18. – Monte Carlo simulation results for a low-cost airport, option value, CCF model, including financial variables.

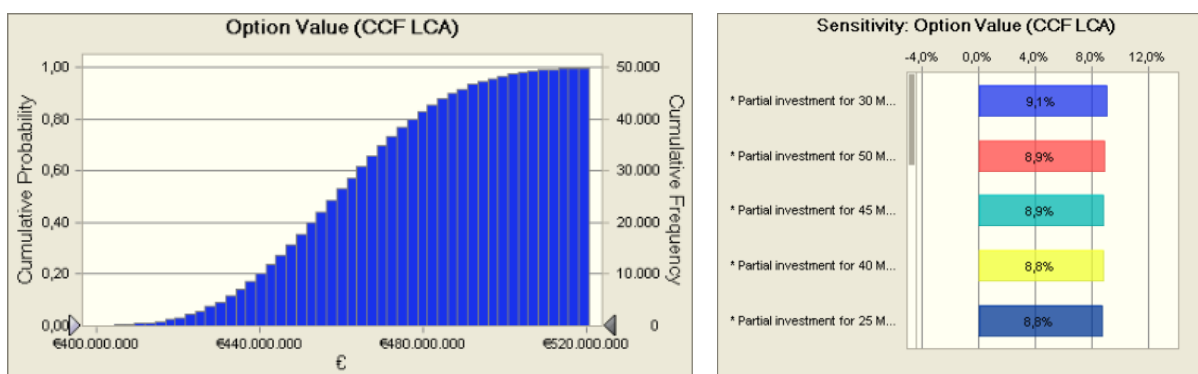


Table A.59. – Monte Carlo simulation results for a low-cost airport, option value, CCF model, including financial variables.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	378.877.928 €
Mean	460.011.571 €	10%	432.461.385 €
Median	459.557.543 €	20%	441.394.639 €
Standard Deviation	21.559.253 €	30%	448.029.043 €
Skewness	0,1212	40%	453.844.551 €
Kurtosis	2,81	50%	459.557.449 €
Coefficient of Variability	0,0469	60%	465.169.000 €
Minimum	378.877.928 €	70%	471.156.015 €
Maximum	539.882.479 €	80%	478.381.812 €
Range Width	161.004.551 €	90%	488.399.328 €
Mean Std. Error	96.416 €	100%	539.882.479 €

Figure A.19. – Monte Carlo simulation results for a low-cost airport, equity beta.

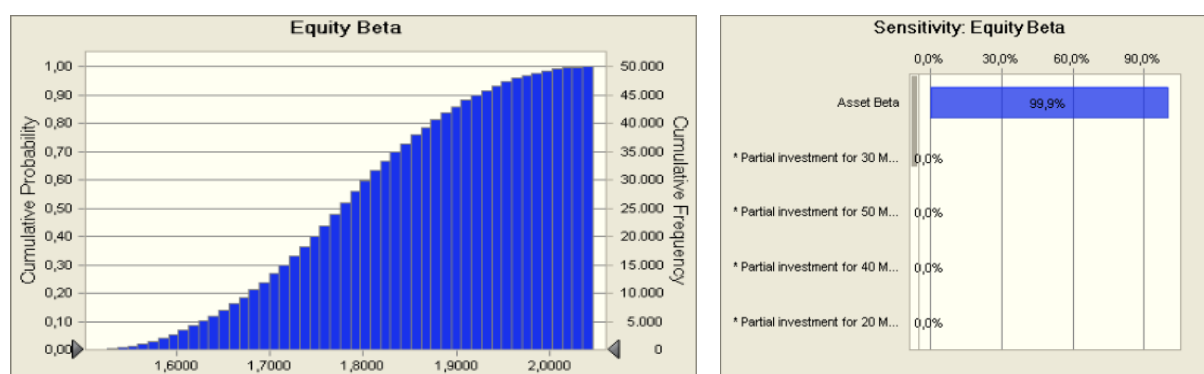


Table A.60. – Monte Carlo simulation results for a low-cost airport, equity beta.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	1,5144
Mean	1,7808	10%	1,6331
Median	1,7810	20%	1,6836
Standard Deviation	0,1086	30%	1,7212
Skewness	-0,0025	40%	1,7532
Kurtosis	2,41	50%	1,7810
Coefficient of Variability	0,0610	60%	1,8086
Minimum	1,5144	70%	1,8408
Maximum	2,0464	80%	1,8783
Range Width	0,5320	90%	1,9273
Mean Std. Error	0,0005	100%	2,0464

Figure A.20. – Monte Carlo simulation results for a low-cost airport, cost of debt.

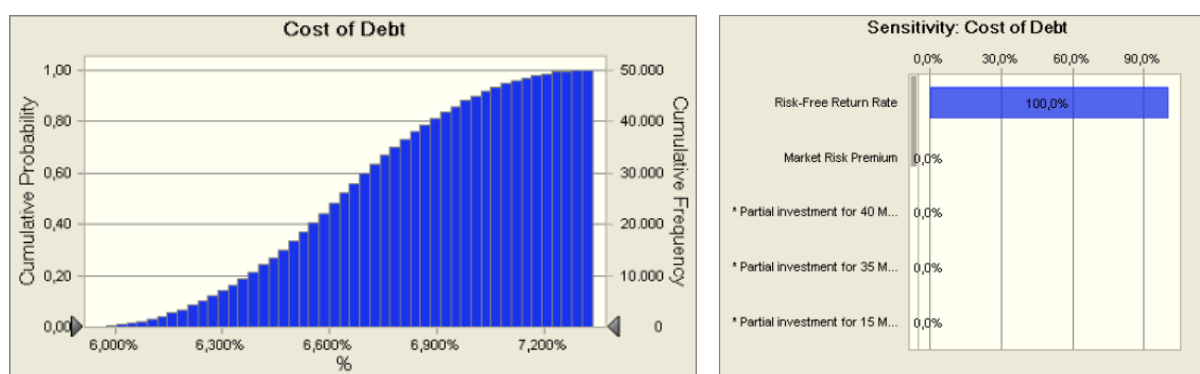


Table A.61. – Monte Carlo simulation results for a low-cost airport, cost of debt.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	5,948%
Mean	6,641%	10%	6,257%
Median	6,641%	20%	6,385%
Standard Deviation	0,284%	30%	6,485%
Skewness	-0,0019	40%	6,567%
Kurtosis	2,40	50%	6,641%
Coefficient of Variability	0,0427	60%	6,715%
Minimum	5,948%	70%	6,798%
Maximum	7,335%	80%	6,897%
Range Width	1,387%	90%	7,024%
Mean Std. Error	0,001%	100%	7,335%

Figure A.21. – Monte Carlo simulation results for a low-cost airport, cost of equity.

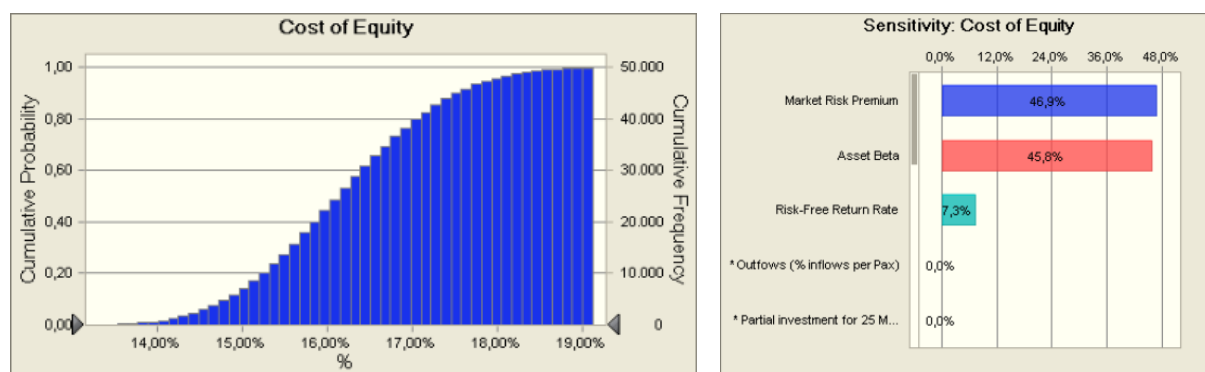


Table A.62. – Monte Carlo simulation results for a low-cost airport, cost of equity.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	12,96%
Mean	16,21%	10%	14,88%
Median	16,19%	20%	15,31%
Standard Deviation	1,04%	30%	15,64%
Skewness	0,1133	40%	15,92%
Kurtosis	2,75	50%	16,19%
Coefficient of Variability	0,0641	60%	16,46%
Minimum	12,96%	70%	16,76%
Maximum	19,88%	80%	17,11%
Range Width	6,92%	90%	17,58%
Mean Std. Error	0,00%	100%	19,88%

Figure A.22. – Monte Carlo simulation results for a low-cost airport, expected asset return.

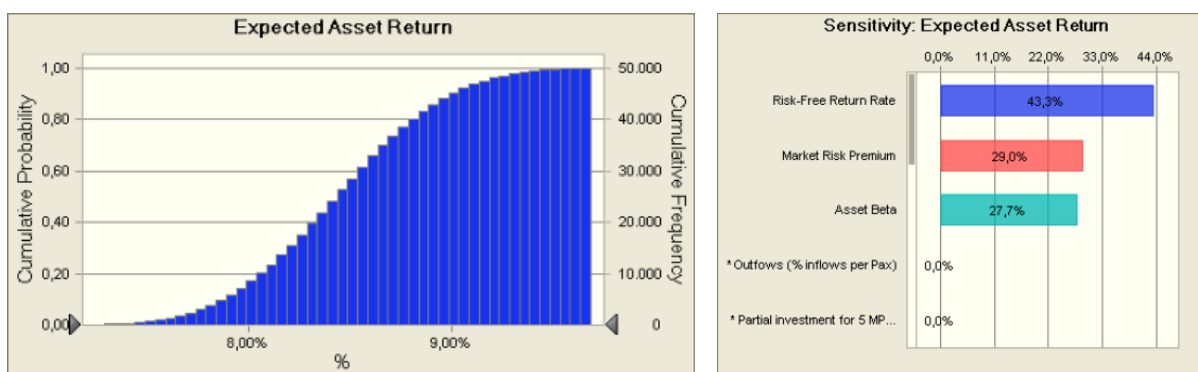


Table A.63. – Monte Carlo simulation results for a low-cost airport, expected asset return.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	7,02%
Mean	8,46%	10%	7,90%
Median	8,45%	20%	8,08%
Standard Deviation	0,44%	30%	8,22%
Skewness	0,0609	40%	8,34%
Kurtosis	2,80	50%	8,45%
Coefficient of Variability	0,0515	60%	8,57%
Minimum	7,02%	70%	8,69%
Maximum	10,05%	80%	8,83%
Range Width	3,03%	90%	9,03%
Mean Std. Error	0,00%	100%	10,05%

Figure A.23. – Monte Carlo simulation results for a low-cost airport, WACC.

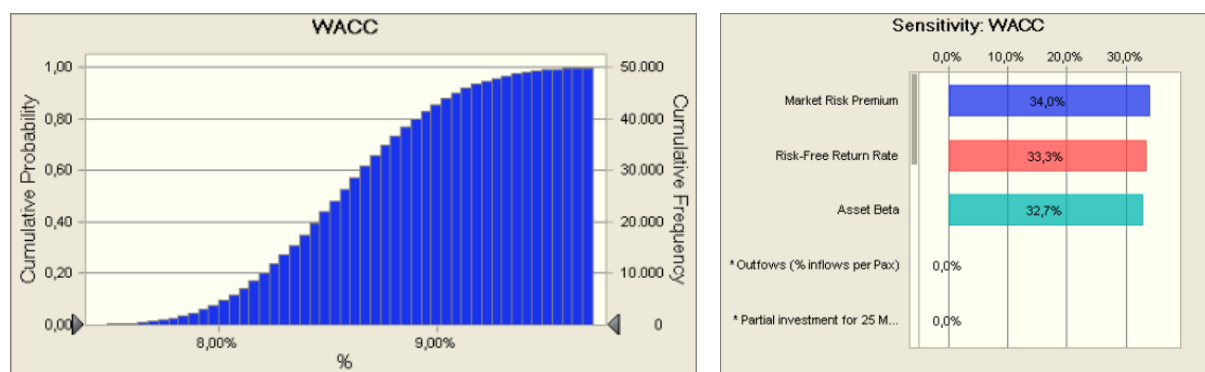


Table A.64. – Monte Carlo simulation results for a low-cost airport, WACC.

Statistics	Forecast values	Percentiles	Forecast values
Trials	50.000	0%	7,25%
Mean	8,58%	10%	8,06%
Median	8,57%	20%	8,23%
Standard Deviation	0,40%	30%	8,36%
Skewness	0,0745	40%	8,47%
Kurtosis	2,80	50%	8,57%
Coefficient of Variability	0,0470	60%	8,68%
Minimum	7,25%	70%	8,79%
Maximum	10,06%	80%	8,92%
Range Width	2,81%	90%	9,10%
Mean Std. Error	0,00%	100%	10,06%