Tackling Uncertainty in Airport Design: A Real Options Approach

by

Richard-Duane Chambers

Bachelor of Science, Aerospace Engineering
Massachusetts Institute of Technology, 2005

Submitted to the Engineering Systems Division
in Partial Fulfillment of the Requirements of the Degree of

Masters of Science in Technology and Policy

at the

Massachusetts Institute of Technology

September 2007

Signature of Author ……………………………………………………………………………………...
Technology and Policy Program, Engineering Systems Division
August 14, 2007

Certified by………………………………………………..………………………………………………
Richard de Neufville
Professor of Engineering Systems and of Civil and Environmental Engineering
Thesis Supervisor

Accepted by………………………………………………..……………………………………………...
Dava J. Newman
Professor of Aeronautics and Astronautics and Engineering Systems
Director, Technology and Policy Program

(This page intentionally left blank)

Tackling Uncertainty in Airport Design: A Real Options Approach

by

Richard-Duane Chambers

Submitted to the Engineering Systems Division on [Date of Signing]
in Partial Fulfillment of the Requirements for
the Degree of Master of Science in Technology and Policy

ABSTRACT

The airport industry is changing. Once understood as stand-alone public infrastructures, many modern airports now operate within privatized multi-airport systems and contend with previously unknown competitive pressures. As a result, many of the same airports which once enjoyed natural monopolies and government protections must now compete with secondary facilities both for airline patronage and for passenger traffic. Further, changes in the airline industry such as the success of the low-cost carrier, ongoing consolidation, and possible changes to the hub structure now threaten to impose new demands on airport services. In this environment, airport owners are being made to tackle not only significant uncertainty in traffic levels and passenger demand but also the sometimes conflicting needs of varying airline customers.

By referencing the experiences of airports across Europe and the US, this paper seeks to highlight strategies for confronting these uncertainties. In particular, research conclusions focus on providing flexible responses that may prove useful given the continued growth of multi-airport systems, expansion of low-cost carriers, and associated industry restructuring.

To this end, this thesis presents methodologies for evaluating the financial benefits which may be accrued through applying real options principles at new and developing airports. Two evaluative models, one focused on the construction of airport runway systems and the other on airport terminal design, are presented. Each model – as developed by the author – is designed to permit the simple application of economic and decision analyses in order to gauge the possibility of success in terms of airport cost, accessibility, and patronage. The models are therefore particularly useful for the preliminary evaluation of various airport development strategies, especially within educational contexts. The development of a second major airport outside of Lisbon provides the central case study.

Thesis Supervisor: Richard de Neufville
Title: Professor of Engineering Systems and of Civil and Environmental Engineering

(This page intentionally left blank.)

ACKNOWLEDGEMENTS

First and foremost, I would like to extend my appreciation to my advisor, Professor Richard de Neufville. Were it not for his knowledge and instruction, I would certainly have been quite overwhelmed. Moreover, it was his exemplary patience, guidance, and support which truly empowered me to complete this thesis.

Similarly, I would like to express my gratitude to Professor Joseph Sussman, who gave me the opportunity to complete this research, to the MIT-Portugal Project, which funded my efforts, and to Boyana Petkova and the colleagues who labored alongside me. Though I admit that working on this thesis has at times been arduous, tiring, and troublesome, I am forever grateful to the many individuals who allowed me the opportunity to complete it. I only hope that my work will add a fraction of the value it gave to me to those who read it.

Finally, I would be entirely remiss if I did not sincerely thank the numerous advocates and mentors who have permitted me to come this far. I have truly stood on the shoulders of people better than I. To my mother and father who have sacrificed for me at every turn, thank you. To my sister, grandparents, aunt and uncles who have believed in me even when I could not, thank you. To my teachers, Mr. Balkcom, Ms. Hartman, and the many more of you who have supported me in the face of illness and adversity, thank you. To the men who have mentored me through MIT and given me opportunities I hardly knew I could have, Keith Santarelli, Jayakanth Srinivasan, and especially Professor Wesley L. Harris, you have my eternal gratitude. To my God and to my Church who have given me strength, you have my ongoing praise. And, last but not least, to my friends, you are truly exceptional. You have toiled with me through late nights; you have fed me, distracted me, and kept me sane; you have kicked (Tae Kwon Do) with me at all hours; you have given me confidence when I lacked it and humility when I needed it; you have constantly made me better than I was before. Thank you all.

With Sincerity,

Richard-Duane Chambers

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

The implementation of a successful airport system faces significant uncertainties, both in design and management. Along with fluctuating customer requirements, unpredictable demand growth and ongoing technological shifts, changes in the airline industry and in government policy can cause substantial deviations from predicted revenues and service levels. As a result, maintaining the flexibility to adapt to changing circumstances during each stage of the airport lifecycle can offer significant benefits.

This thesis, by focusing on the concept of real options design, aims to reveal value-enhancing methods for incorporating flexibility into modern airports. Further, it seeks to adapt the notion of flexibility so as to inform airport policymaking in the public and private sectors. The central hypothesis – given high uncertainty, flexible designs can simultaneously reduce costly planning errors *and* increase project value – has already been proven. Research within the petrochemical (Babajide, 2001), satellite (de Weck, de Neufville, & Chaize, 2004), road transportation (Hodota, 2006), and even air transport (de Neufville & Odoni, 2003) industries, for instance, demonstrate that alternative growth strategies at each stage of project development allow stakeholders either to capitalize on unforeseen opportunities or to mitigate the effects of misfortune. However, the effect of continuing changes in air transportation such as the growth of low-cost carriers and multiple airport systems leaves room for further study. The work presented here attempts to address this gap.

In pursuing these goals, the thesis expands upon previous work demonstrating that traditional, rigid master planning is unsuitable for airport design (Odoni & de Neufville, 1992) and highlighting flexible airport configurations (de Neufville, 1996). The ultimate research goal is to demonstrate the value of these alternate, real options methods in the design, construction, and development of airport systems.

1. Study Rationale

Historically, traditional inflexible planning methods have led to several expensive failures. As a result, multiple over-designed airports have lacked the ability to adapt to changing traffic levels, technologies, and customer demands. For instance, while Washington/Dulles's facilities remained underused for 20 years (de Neufville, 1995), Canada's costly Montréal/Mirabel will likely close due an inability to attract customers. In both cases, the airports suffered due to an inability to either predict or direct future states.

Ongoing trends in the airport and aviation industries do not augur greater predictability. Instead, both continued deregulation and the growth of smaller, secondary airports suggest increasing hardships in determining traffic flows. Due to increased competition, planners may no longer assume that large, metropolitan airports will attract the lion's share of nearby air-travelers based on location alone. Equally important, the ongoing success of the low-cost carrier has created disparate demands on airport design. As a result, airport planners must now prepare to accommodate large network carriers (NC) and new low-cost carriers (LCC) despite different standards for terminals, passenger facilities, congestion levels, and even airport fees. Together, these trends imply greater difficulties in both forecasting and attracting airport traffic and belie the notion that airports can be constructed in a rigid "one-size-fits-all" fashion.

Given that the current development of the aviation industry suggests increasing uncertainty in passenger traffic and customer requirements, proper airport design is essential to financial success. Further, the ability to counter uncertainty in the development of airports is gaining in importance. Revealing the usefulness of flexible planning in dealing with this challenge is therefore the central aim of this thesis.

2. Research Methodology

The research employs analytical tools common to real options theory including projections of traffic through binomial lattices, decision tree analysis, and the calculation of project worth through net present value. Sources of uncertainty in the development of airport systems were determined through an extensive literature review. As a result, major trends such as deregulation, increased airport competition, and the growth of low-cost carriers were identified in order to inform the thesis and its models. Simultaneously, the literature review also revealed examples demonstrating the ability of different planning methods to mitigate uncertainties. The thesis' various conclusions are therefore bolstered through a series of references to airports worldwide. Finally, the completion of a representative case study focusing on the development of a major new airport in Portugal is meant to prove the applicability of a flexible planning approach to airport development.

Economic Analysis

Given that economics is a primary driver in airport development and maintenance, this study's analyses largely focus on the ability of airport planners to recover costs and to create profits within a given time period. Only revenues internal to the airport are considered, though the models can be reconfigured to account for external factors (i.e. regional economic benefits resulting from airport development).

Due to the long lifespan of an airport system, all economic calculations within this thesis account for the "time-value of money", a concept which states that a given amount of money is more valuable to an investor today than in the future. As a result, the valuation of each flexible alternative rests upon the determination of net present value (NPV), wherein the worth of an investment is derived by converting future cash flows to represent their current worth. The use of the net present value approach was selected as it represents common industry practice for long term-financial planning.

Other considerations important to the economic analyses include the ability of the airport to inexpensively meet changing capacity requirements or to undertake modifications in order to service new or returning customers. Value-at-risk (and value-at-gain), or the total losses (or gains) which may be incurred given the performance of the airport system, is also considered.

All calculations are facilitated through Microsoft Excel©, which is generally suited both to handling problems of this size and to providing comprehensible instruction regarding the valuation of flexibility.

Binomial Lattice Model

A binomial lattice model simulating probable demand projections for the case airport in Portugal is used in order to determine possible economic returns. The binomial model is useful as it directly accounts for the effects of uncertainty, given a historically determined growth pattern and standard deviation.

Decision Tree

In instances where assuming a particular growth pattern over several years is impossible or inappropriate (due to the likelihood of significant changes in past trends) or where several different decisions are possible during varying periods of system evolution, a decision tree analysis was found to be more useful than the standard binomial model. Therefore, the use of decision trees in this study is meant to bolster the research conclusions by helping to explore cases in which airport planners cannot assume future growth patterns or must account for more complex flexible alternatives. The evaluation is designed to illustrate a particular methodology for decision-making rather than to imply a set of correct actions for a particular airport. As before, net present value provides the primary metric for comparing flexible and rigid designs.

Selection of Reference Airports

This study references the relative success and failure of various airports worldwide in order to illustrate the value of flexible design. Reference airports have been chosen in order to represent the influence of low-cost carriers, multi-airport systems, and demand volatility on airport systems.

Central Case Study

Finally, a case study approach has been applied in order to test the thesis' central hypothesis regarding flexibility and added value. As such, conclusions drawn through the review of existing flexibility literature as well as from an examination of various international airports have been applied to the development of a national air transportation system in Portugal, where the government intends to build a secondary airport outside of Lisbon while developing a series of regional airports to better connect various regions. Given the test environment chosen, special attention is given to the influence of low-cost carriers and to the development of multi-airport systems, thereby leading to suggestions regarding the applicability of real options thinking in the initial development of niche, low-cost markets for new airports and to ensuring the flexibility required for continued growth outside of that niche.

As a research tool, the case study is further intended to assess the hypothesis that employing real options theory to inform the incremental development of airport systems and to allow airports to flexibly adapt to changing passenger levels and industry standards has quantifiable financial benefits.

3. Pedagogical Goals

Aside from exploring its central hypothesis, this thesis further aims to instruct the reader in the understanding of real options theory and the use of applicable tools. As a result, much of the work encapsulated here is intended to be instructional. Small mathematical examples accompany the introduction of several key concepts; in addition, the thesis presents a workable Microsoft Excel© structure for analyzing the benefits of several real options concepts in the development of a modern airport.

4. Thesis Structure

Chapter 1 – Summarizes the theories and valuation methods central to the thesis while presenting the central hypothesis that designing flexibility into a system can create value, especially when uncertainty about future states is high.

Chapter 2 – Provides an overview of the modern airport industry, the uncertainty it currently faces, important trends, and the valuation methods currently employed. Further, it highlights important problems with current airport planning methods and provides a baseline for comparison against the new planning methods proposed by this document.

Chapter 3 – Introduces the theory of real options, complete with its development history, valuation methodology, and applicability to systems replete with uncertainty.

Chapter 4 – Expands the purview of real options theory in order to make it applicable to the development of an airport system. In so doing, it highlights design practices which may prove useful to airport stakeholders at the national, regional, and private sector levels.

Chapter 5 – Illustrates the usefulness of flexible design as demonstrated through application to the development of a major new airport in Portugal.

Chapter 6 – Concludes by presenting findings regarding the application of a flexible design approach to the creation of airports, as can be drawn from the literature review, economic analysis, and case study valuation.

CHAPTER 2: UNCERTAINTY AND THE TRADITIONAL AIRPORT

Chapter 2 – Provides an overview of the modern airport industry including common planning methods, important trends, and well-known sources of industry uncertainty. Further, it discusses the growth of the low-cost carrier and the multi-airport system from the perspective of the increasing uncertainties which they introduce to the planning process.

Airport decision-making occurs on several levels. Within Europe and the United States, for instance, supra-national, national, regional and local bodies each influence important decisions ranging from airport size and location to whether an airport is constructed at all. Whereas the upper echelons of government generally concern themselves with creating transportation gateways to support (inter)national cohesion and economic development, locals tend to focus not only on the home economy but also on environmental issues such as pollution, noise, and the destruction of local norms (Caves & Gosling, 1999). This convergence of different interests makes airport planning a complicated and lengthy process. As a result, facilities such as Denver International Airport (DIA) and Munich/ Franz Josef Strauss (MUC) have suffered due to changing or unforeseen stakeholder requirements. Denver's cost more than tripled from a projected US $1.5 billion to US $5.3 billion partially because the main airline demanded late design changes; Munich's Strauss, though being one-tenth the physical size of Denver International and serving 7/10 the number of passengers in 2005, opened three decades after planning began at a cost of over US $7 billion largely due to environmental litigation issues (Dempsey, 2000).

Together, DIA and MUC offer examples of a common difficulty. Every airport – whether constructed as a national symbol, local travel hub, or regional source of wealth and power – is subject to significant uncertainty. Capital costs, time-to-completion, and traffic flows are only the first of many unpredictable factors. Because airports survive based on their ability to provide a useful service, they must also contend with fluid government interests and the changing needs of their primary customers (airlines and passengers) over a long period of operation. Unfortunately, traditional airport planning methods have not always provided the key to success. Indeed, different variations on airport planning have come and gone while the problem of uncertainty has remained, ever vibrant. This chapter introduces different airport planning methods, focusing mainly on master planning, the most prominent technique. Further, it attempts to identify weaknesses in common planning techniques by detailing several uncertainties which often obfuscate the planning process.

1. Master Planning: An Introduction

Antonín Kazda and Robert Caves, authors of *Airport Design and Operation*, describe the airport master plan rather favorably both as a construction plan that envisions the maximum development of the site and as a guide for the advancement of its facilities (Kazda & Caves, 2000). Within this context, several other benefits become apparent. Airport master plans, because they describe the airport's size, layout, and costs, are useful in the creation of key milestones and in delineating possible profits. Further, they help national and regional governments ensure that each airport under their purview helps to promote common goals and provide an important blueprint for airport owners and managers. In theory, the process of creating a master plan should also ensure the useful involvement of airport stakeholders on every level. The process defined by the International Air Transport Association (IATA), for instance, includes a review of national planning strategies, an appraisal of community sentiments, and various revisions of the airport development strategy (IATA, 2004).

In an attempt to garner these benefits, airport planning organizations worldwide subscribe to the master planning model in some form. Although the procedures for formulating master plans may differ by nation, significant commonalities in the planning process do exist. In fact, a review of planning literature produced by the International Civil Aviation Authority (ICAO) (ICAO, 2006), International Air Transport Association (IATA) (IATA, 2004), United States Federal Aviation Administration (FAA) (FAA, 2005), and United Kingdom Department for Transport (DfT) (DfT, undated) shows several similarities. The basic elements, as aggregated and presented roughly in order of completion, are as follows:

1. Current environment survey
2. Aviation activity forecasts
3. Evaluation of airport alternatives
4. Facilities implementation plan
5. Financial Analysis

The following subsections describe the purpose and methodology of each.

<u>Current Environment Survey</u>

The airport master planning process generally begins with an examination of existing conditions. This encompasses several factors starting with environmental restrictions, regional socio-economic indicators, an inventory of political players, and a description of the geographic location. Given data on regional travel patterns, economic growth, and historical aviation activity, airport planners determine how best to adapt the airport business model to its region. In cases where the airport under investigation already exists, the current environment survey also includes an inventory of current facilities.

<u>Aviation Activity Forecasts</u>

Aviation forecasting is central to master planning; in essence, it provides the basis for each successive step in the planning process. The required forecasts come in a multitude of forms: airport planners generally require speculative data on aviation activity in terms of the number of aircraft operations, passenger types and aircraft mix over the short term (5 years), medium term (10 years), and long term (over 10 years). In addition, planners often demand far more detailed information on future occurrences such as the amount of passengers served during the busiest hour of the busiest day of the typical year.

Numerous inputs (many of which can prove quite difficult to measure) inform the generation of these forecasts. The FAA, for instance, suggests that the master plan account for future trends in regional business and economic activity, the activity of competitor modes of transportation, and possible future trends in aviation including airline mergers and new aircraft technologies. Other important factors include local demographic indicators such as the average amount of leisure time, favored recreational activities, and the level of disposable income per capita. The list does not stop there; rather, forecasters can find themselves incorporating an ever increasing number of data points including – but not limited to – the distance between urban centers in the airport region, the influence of local politics and taxes, fuel costs, and shifting attitudes toward air transport.

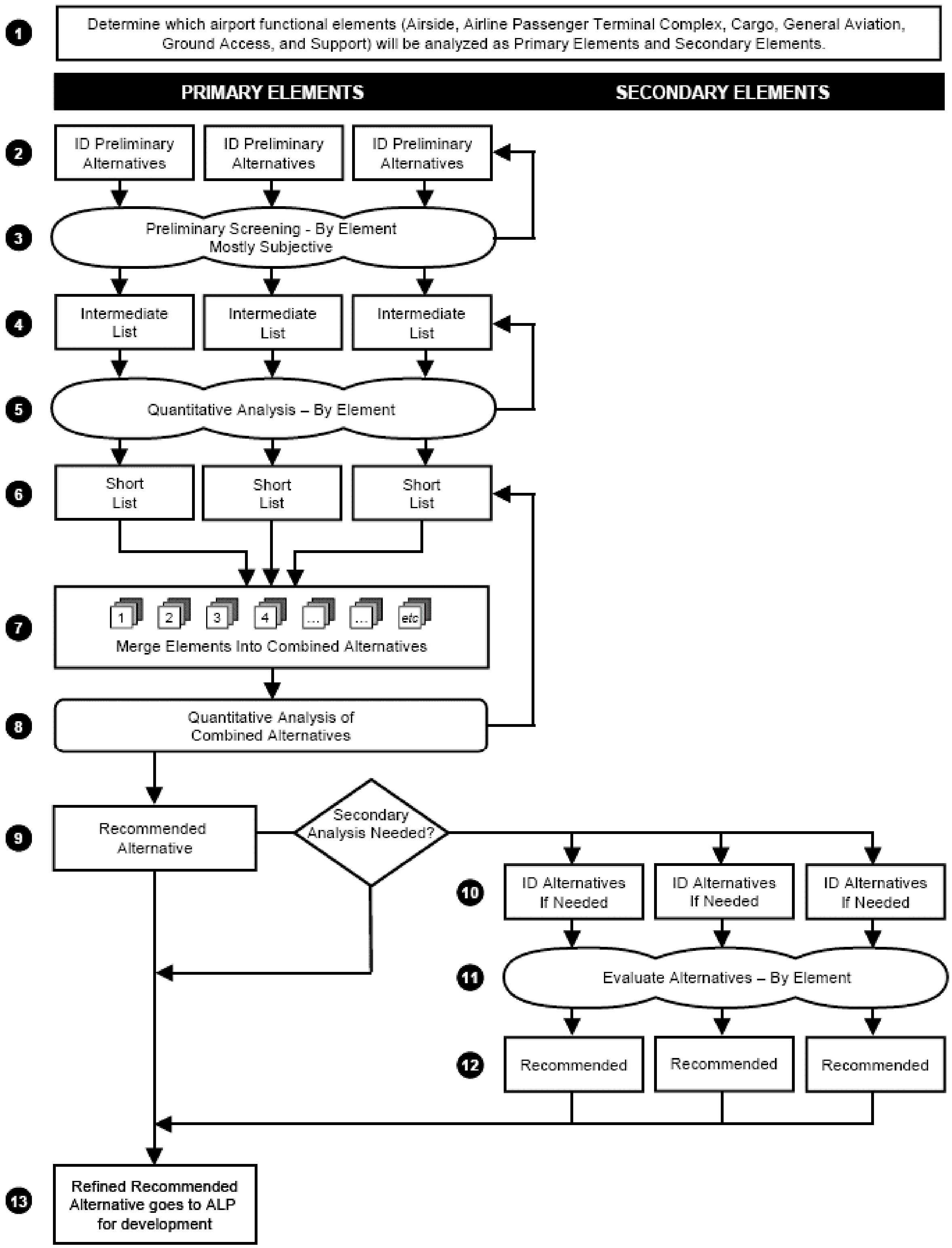
Once data are gathered, forecasters may choose from several possible methods to predict the future. The ICAO forecasting manual (ICAO, 1985) and the FAA Advisory Circular on Master Planning (FAA, 2005) name the most common techniques: trend projection, econometric forecasting and regression analysis, and market surveys. Whereas trend analysis extrapolates future states based on historical patterns, regression analysis and econometric forecasting use statistical methods to account for changes in several different variables. Market analysis, on the other hand, attempts to determine the local demand for air transport as a function of competition for predicted national or regional demand. Each method, of course, has particular strengths and weaknesses which makes it more appropriate for particular forecast time periods, airport size, and regions.

Evaluation of Airport Alternatives

Once forecasts have been finalized, airport planners focus on creating different strategies for accommodating the predicted level of activity. In doing so, planners must account for the capacity required in the airfield, airspace, and airport landside. Further, they attempt to correctly size car parks, determine an adequate number of personnel, account for security considerations, and uphold a particular strategic vision for the airport project under review.

As before, the process is multi-tiered. Aside from separating the various airport elements and ordering them based on importance, airport planners are generally required to create multiple designs for individual areas (terminals, airside, and transportation, etc.) and to produce various airport layouts. Planning for capacity is particularly intricate, as the process often requires translating yearly demand forecasts into an estimate of how many passengers the airport will have to serve at a given moment. Though the exact procedure differs by nation, the idea is the same: designers use a series of historically determined multiplicative factors to transform the forecast of passengers per year into a forecast for the number of passengers served in the busiest hour of the busiest day. This result is then used to size airport facilities. Once this process is complete, airport managers then choose from a multitude of possible alternatives for airport development, quite often opting for a development path meant to survive the airport's lifetime.

Figure 2-1: FAA Process for selecting among alternatives (FAA, 2005)



Facilities Implementation Plan

Next, the master planning process calls on its proponents to finalize their decision choices by creating an airport layout plan (ALP), which is a graphic representation of the expected evolution of facilities over the airport lifetime. The ALP, further, can provide a blueprint for airport development, show expected land-use patterns on and around the airport site, and provide possibilities for surface access.

In addition to the formation of an airport layout plan, this stage of master planning often includes the formation of a schedule for airport development, again corresponding to the short-, medium-, and long-term. This schedule, in addition with the airport capital improvement plan (CIP), ideally encompasses a description of all planned airport facilities, settles on dates for their construction and opening, and assigns activities and responsibilities to key stakeholders.

Financial Analysis

Finally – and quite importantly – airport master planners close by examining the financial feasibility of the airport, as constructed to the specifications defined by the survey of local conditions and forecast-determined capacity requirements. Although an evaluation of benefits and costs is important during each stage of master planning, common practice often leaves the determination of financial feasibility until after a capital improvement plan is complete (Crites & Bauman, 1998). This final stage then, demonstrates the sponsor's ability to fund the airport project based on an accounting of various funding sources and an analysis of expected cash flows. Given that the sponsor is able and that the master plan can survive public scrutiny, the master planning process is complete and airport construction can move forward.

2. Master Plans Complicated: The Role of Uncertainty

Although master planning provides the standard for airport development, the process is not without its detractors. For example, Paul Stephen Dempsey commented that the "FAA's airport planning model only provides an idealized approach that cannot produce optimal results" (Dempsey, Goetz, & Szyliowicz, 1997, p.492). This criticism cannot be limited to the FAA though: indeed, FAA procedures closely mirror the standards propagated worldwide.

Other commentators have lodged similar complaints with the master planning process, many of which share a common thread. According to detractors, forecasts – regardless of method – present an idealized and consistently incorrect vision of the future. Even Kazda (who is quoted above highlighting the benefits of master planning) notes that though it is "sensible to predict requirements perhaps 35 years ahead … the ability to predict even 15 years ahead is questionable" (Kazda & Caves, 2000, p.7). In reality, most instances permit the creation of several conflicting forecasts depending on the forecast method and on the assumptions made regarding regional economic health, local regulations, population growth, and passenger demands. Therefore, no single forecast can be entirely correct; small disparities in assumption can yield large differences.

Further, the linearly designed master planning process is primarily reactive; it provides little means of proactively controlling for the numerous uncertainties which reduce its benefits. Despite this, planning for multiple scenarios is often eschewed. FAA reviews of airport planning, for instance, focuses on one "most-likely" scenario. As a result, traditional airport design, being dependent on fixed forecasts, is susceptible to any number of uncertainties common to transportation systems.

Finally, master planning has proven prone to error. Even with a single forecast, the master planning process tends to falter when translating traffic predictions into functional designs. As in the case of determining peak hour traffic, the usefulness of the procedure hinges on the expectation that historical trends predict future outcomes and is highly subject to minor assumptions and misinterpretation (Odoni and de Neufville, 1992). In sum, the master planning process, by creating inflexible designs specifically suited to a particular forecast, has led to several expensive missteps.

Of course, airport planning is not alone in these particular weaknesses. The following sections describe the uncertainties that plague transportation systems in general and airports in specific.

<u>Uncertainty in General Transportation Systems</u>

The aviation industry is not unique in its susceptibility to significant uncertainty. To the contrary, public works – and specifically transportation systems – have been shown to exhibit significant disparities between expected and actual values in construction costs, time to completion of facilities, and passenger throughput. Simply phrased, the forecast is "always wrong".

Cost estimations and traffic forecasts, which together determine profitability and viability, are particularly prone to misestimation. According to one study, nine out of ten transportation infrastructure projects cost more than originally predicted; the phenomenon is both global and time-insensitive (Flyvbjerg, 2002). In addition, any number of factors can quickly accrue to undermine forecasting: Petkova, for instance, shows that inputs ranging from oil prices to GDP – each of them requiring their own forecasts – can affect the predictability of traffic demand (Petkova, 2007).

Incorrect traffic forecasts are similarly common but perhaps more damaging. Because incorrect traffic forecasts bias the value of an investment, they can lead to the construction of expensive but underused facilities. Montréal Mirabel Airport (YMX), for instance, was constructed in 1975 in expectation of some 40 million passengers by 2025; however, the airport failed to attract enough traffic to support continuing operations and was closed to passenger traffic in 2004 (Canadian Press, 2006). In addition, overly pessimistic or generous traffic forecasts can negatively affect the size and engineering characteristics of the transportation system. Bangkok's two billion dollar (US $2 billion)

Skytrain, for one, suffers from oversized platforms, idle cars, and multi-million dollar inefficiencies because passenger forecasts exceeded actual traffic levels by 250% (Flyvbjerg, 2005).

Airport systems have proven quite prone to these difficulties. One study of traffic forecasts for major New England airports, for instance, showed an average discrepancy between predicted and actual traffic of 23% for five-year forecasts and 78% for 15 year forecasts (Maldonado, 1990). Nonetheless, it appears that forecasters continue to incorrectly ascribe to the "myth of predictability": in assuming that future states will necessarily be determined by today's trends, planners subject their projects to the risks of under-utilization and obsolescence (Caves & Gosling, 1999).

Back to Airports: Established Sources of Uncertainty

The large discrepancies which weaken forecasts emanate from several different – and at times conflicting – sources. Externalities such as fluctuations in local and global economies, changes in technologies and regulations, and the arrival of new market participants as well as internal factors such as industry restructuring can each have important though unpredictable effects. In fact, previous studies demonstrate that long-term forecasts generally are more likely than not to be at least 20% off from reality (de Neufville, 1991a).

Table 2-1: Unreliability of Forecasts (Adapted from Maldonado, 1990)

PLANNING HORIZON	F/A RATIO CHARACTERISTICS		
Years	Range	Std. Deviation	Error Range (Half Beyond)
FIVE	0.64 - 1.96	0.30	23%
TEN	0.58 - 2.40	0.54	34%
FIFTEEN	0.66 - 3.10	0.69	76%

F/A Ratio = Forecast Values / Average Values

Although volatility of demand is particularly important and is therefore highlighted throughout this document, the following list of uncertainties is meant to more fully address several areas of airport planning.

Economic Shifts

Unlike in other transportation systems, air travel tends to impose relatively high customer costs. Therefore, the air transport industry is particularly sensitive to unforeseen changes in regional economic health. This principle carries for both business and leisure travelers. Whereas airports in areas of increasing economic importance and wealth may simultaneously expect more incoming business travel and increased outgoing tourism, airports in declining economies may fairly expect an overall decrease in traffic as former customers either avoid the region entirely or choose cheaper transportation alternatives.

As a result, an economic downturn within an airport's home region could not only negatively affect the number of businesspeople visiting the area but also depress the number of tourists leaving the region for short trips. Even relative economic shifts – rather than actual economic decline – can cause negative effects. Canada's Mirabel, for example, suffered as the increasing economic importance of Toronto made Montréal less attractive as Canada's gateway city (Hall, 2004).

Regulatory and Technological Change

Technological change can have multiple impacts. Consider, for instance, the case of the Airbus A380, which is slated to enter the aviation market in 2007 as the world's largest aircraft. Aside from changing the expected throughput of airports served by the new aircraft, the introduction of the A380 also portends changes in airport physical design. Certainly, larger aircraft carrying more individuals may require larger runways, more efficient luggage carriage, increased area for processing passenger traffic, and so forth. Past experience has proven the lesson: on a smaller scale, the introduction of e-ticketing has prompted the development of more efficient terminal check-in areas worldwide.

In much the same way, new regulations can demand different airport designs, alter airport financing methods, or introduce unforeseen traffic volatility. In fact, new regulatory schemes have created some of the most important trends in aviation and airport design. Thus, Europe, Australia, and the United States have each witnessed the formation of low-cost airlines and their parallel airport networks following deregulation and privatization initiatives within the airline industry.

Competition

Recent trends in the development of communication and transportation systems have exposed airports to uncertainty due to an increasing competition for customers. This effect is compounded by the nature of the aviation product: very few people purchase an airline ticket for the sake of flying. Rather, an airline ticket is simply a means to an end; the ticket represents an opportunity to travel or to assemble with others. Consequently, air travel must compete with other methods of travel or assembly. Thanks to modern technologies, today's airport customer may choose from among multiple alternatives. Whereas high-speed rail now provides rapid connections between several cities, advances in internet communication permit many individuals to forego traveling altogether.

Those who opt to fly have also gained more choices and, in many cases, may now select to travel to/from their airport of choice. In past, this vulnerability had been rather limited; only airline hubs competed on a significant scale for airlines and their transfer passengers. However, it is now true that many non-hub airports can no longer expect to monopolize traffic within a given area; the introduction of multiple airport systems has significantly altered patterns of airport traffic.

Airline Restructuring

Trends specific to the airline industry have also introduced new uncertainties into the planning of airport facilities and the development of traffic forecasts. The advent of the low-cost carrier (discussed below) and the restructuring of the airline industry imply particularly destabilizing effects. Airports which depend principally on a single carrier are particularly susceptible as their financial status and traffic levels are largely tied to that carrier's success, failure, or divestiture. In 1980, for example, the American Airlines decision to shift its base of operations from Chicago/O'Hare created a 20% drop in traffic at that destination. Today, the possibility of airline mergers and hub restructuring may be advancing the possibility of similar events once again.

Public Support and Catastrophic Change

Prevalent trends aside, shifts in public opinion can also create large discrepancies in airport forecasts. Osaka's Kansai International Airport (KIX), for one, was built at great expense by the Japanese government in response to both capacity constraints and complaints regarding noise at Osaka/Itami International Airport (ITM), then the region's main airport. However, once the new airport opened, the public chose to support the noisier Itami rather than to travel to the less centrally located Kansai and the employees at Itami successfully blocked the closure of that airport (de Neufville, 2003).

Public support for the aviation industry in general has also affected the accuracy of traffic forecasts and influenced the success of airport facilities. To be certain, no forecast could have reasonably predicted the effect on passenger travel resulting from the Asian economic collapse of the 1990's, the events of September 11, 2001, or the 2002 SARS outbreak, each of which produced significant negative effects on aviation.

3. Novel Uncertainties: Growth of the Low Cost Carrier

Established sources of uncertainty aside, it appears that the aviation industry must now learn to handle new unknowns. Though long accustomed to economic cycles due to regional changes, new aircraft, and shifting propensities to travel, air transportation has come to bear the effects of deregulation and the creation of a new competitive environment wherein airline restructuring ranging from bankruptcy, divestiture, and even mergers now presage significant transformations in the airport-airline relationship. In effect, changing aviation trends have introduced new uncertainties which must be properly considered during the airport design process.

Of these changes, the growth of low-cost carriers (LCC) such as Southwest and JetBlue in the United States and easyJet and Ryanair in Europe promises the most enduring effects. In an industry previously protected from outside competition by high fixed costs and government intervention, these new airlines have grown substantially by gaining market share from competitors and by increasing the passenger market as a whole. The introduction of LCC, moreover, has in some cases effected ongoing changes not only in the relationship between airlines and airports by promoting an unbundling of services and long-term contracts with joint marketing and risk sharing but also between air and rail travel (Graham, 2004). This leaves airports with the significant responsibility of changing their structure in order to service new LCC customers while maintaining the interests of long-standing airline partners. Equally important, the continued success of low-cost carriers creates many new questions – and therefore uncertainties – for airport designers to handle.

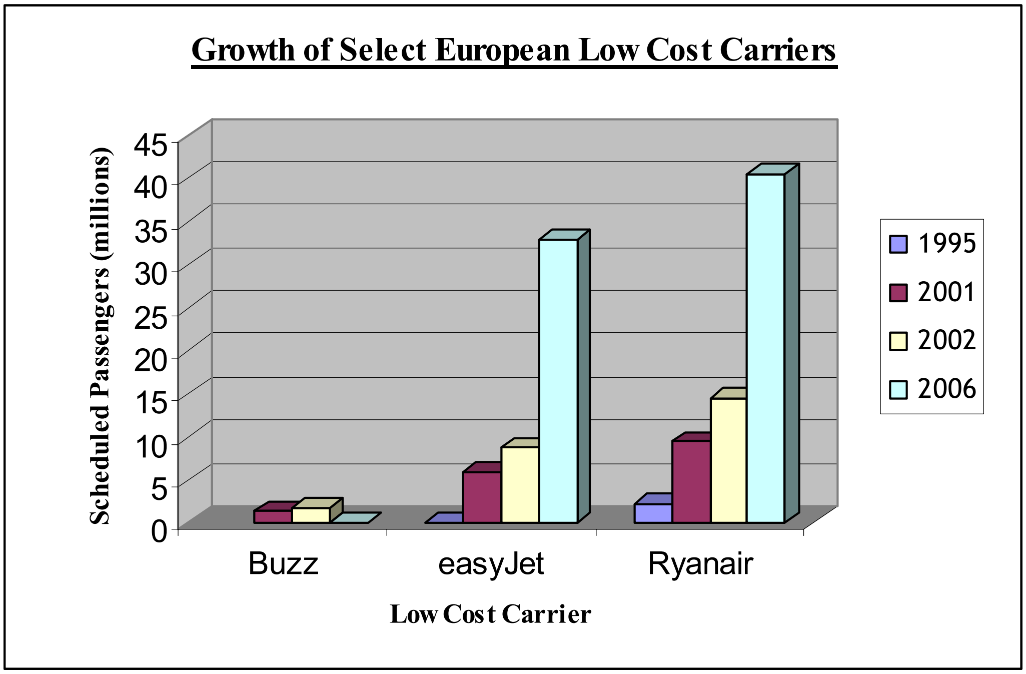
Where will traffic develop?	
	[1] LCC have shown an affinity for secondary airports. [2] LCC are more able to shift operations between airports than NC.
What will be the shape of the airline industry?	
	[1] LCC and NC are competing for market-share. [2] Increasing competition has prompted new mergers and alliances.
What will be the primary source of airline revenue?	
	[1] Low-cost airports generally receive lower aeronautical revenues. [2] Non-aeronautical revenues are gaining in importance.
How should airports be constructed?	
	[1] LCC focus on point-to-point rather than hubbing operations. [2] LCC often avoid airport staples favored by NC. [3] Increased competition among airports may suggest focusing on niche markets.
Which passengers should airports cater to?	
	[1] LCC passengers appear to require fewer airport amenities [2] Some LCC have expressed interest in serving intercontinental routes.

Figure 2-2: Low Cost Carriers: New Questions, New Uncertainties

LCC Characteristics, History, and Growth

One of the most noted low-cost carriers, the United States' Southwest Airlines, entered the aviation market in 1971. Having started with a model of low cost, direct service between three major regional cities, Southwest has expanded its domestic routes to become the third largest airline in the world in terms of the number of passengers carried. Financially, the airline has proven equally successful. With a 2004 market capitalization that exceeded that of all major US airlines combined, Southwest's stock was the best performing in the United States from 1972 to 2002 (Bonamici, 2004).

Due to the intense success of low-cost airlines inside the United States, the low-cost model has been transplanted globally. In Europe, 2006 witnessed the operation of 50 different low-cost carriers the sum of which controlled over 16% of the air passenger market in terms of total flights (Eurocontrol, 2006). At the same time, Europe's major low-cost carriers, easyJet (UK) and Ryanair (Ireland), have experienced growth rates of 25 – 30% per year (Dennis, 2004). Aggressive marketing and cost-cutting measures have further advanced LCC development: experts expect LCC to capture from one-quarter (Mercer, 2002) to one-third (Francis, 2003) of the total passenger market by 2010, yielding serious repercussions for the international and national carriers with which they compete and for the airports which service them.



	1995	2001	2002	2006
Ryanair	2.2 M	9.5 M	14.5 M	40.5 M
easyJet	30 K	6 M	8.8 M	33 M
Buzz	*Founded 1999*	1.4 M	1.8 M	*Sold to Ryanair, 2004*

Figure 2-3: LCC Traffic Growth (*Various Sources*)

This phenomenal expansion is of particular importance to airports because of core differences between the LCC and "legacy" network carrier (NC) customer. Unlike the large legacy carriers which had previously exercised quasi-monopoly power in air transportation, low-cost carriers embrace a business model much different in its customer base, air network, and provision of services by focusing on the more cost-sensitive leisure travel market and providing point-to-point (rather than hub-based) service. Consequently, low-cost carriers and their "legacy" competitors often exert opposing pressures on the design of air routes and of individual airports.

LCC Customer Base

The growth of the LCC in Europe, the United States, and now in Asia appears to rest on two pillars – the provision of low-cost service and the ability to focus on customer segments not emphasized by larger carriers. European low-cost leaders Ryanair and easyJet, for instance, focus on providing air services for travelers seeking to visit friends and relatives. In addition, both have successfully attracted cost-conscious business travelers. By focusing on these groups, LCC have demonstrated an ability to grow the overall passenger market, especially on routes with strong tourist appeal (Dennis, 2004).

According to one study, 40% of those surveyed would not have chosen to travel were it not for LCC offers (Pantazis, 2006). Further, the LCC passenger often has different airport needs, placing more value on low-cost airfare and minimum hassle rather than on distance to airport, departure times, and airport amenities.

No Frills Travel

Catering to cost-sensitive markets holds other important ramifications. In order to minimize ticket prices, low-cost carriers strive to reduce the complexity of their operations. Airlines such as Ryanair and easyJet, for instance, eschew free on-board food, frequent flyer programs, indirect sales through travel agencies, and even printed tickets. Francis notes that, in 2001, over 80% of tickets for travel aboard Ryanair and easyJet were purchased over the Internet (as cited by jvdz.net, 2006). Through these activities, LCC have cut costs and gained the title of "no frills airlines."

Although some have postulated that this model – particularly in Europe – yields poor customer service, the evidence seems to suggest otherwise. Rather, by reducing the available amenities, LCC can provide reliable, convenient service while catering to the customer's most important demand – price. As evidence, a September 2004 survey of UK leisure travelers showed that a significantly higher proportion of leisure travelers would recommend "no-frills" carriers rather than traditional airlines, despite the fact that many LCC have low rankings with regard to leg room, comfort, catering, and cleanliness (Doganis, 2006).

Routes/Destinations

Diverging further from the model espoused by the conventional airlines, low-cost carriers have established a separate network of routes and destinations based on short-haul point-to-point travel (de Neufville, 2002). This parallel network operates quite differently from the traditional hub-and-spoke network used by classical network carriers. Unlike the hub-and spoke archetype which maximizes the productivity and frequency of long-haul routes by aggregating flights at major airports, point-to-point travel serves the LCC base by establishing direct routes between popular destinations and avoiding connections at busy airports. In most cases, these low-cost carriers therefore shun flying into congested major airports by selecting smaller, secondary airports in the region of major hubs and tourist areas. Whereas most large airports are sited on expensive properties chosen for their proximity to major cities and economic centers, airports serving low-cost carriers and their passengers need not follow this standard. Belgium's successful Brussels South Charleroi Airport (CRL), for instance, services its customers from an economically depressed region of the country. In addition, Charleroi's location has allowed it to attract the majority of its passengers from affluent areas nearby which were otherwise not served by a low-cost carrier. Certainly, the development of this parallel network of secondary airports has important implications both for new and operating airports, as is discussed later in this chapter.

Aside from creating a parallel route network in regions already served by traditional airlines, low-cost carriers have also proven adept at choosing destinations which are less attractive to major carriers. In the European Union, this has manifested itself in an LCC focus on "warm-water destinations" attractive to leisure travelers, as evidenced in the Figure 2-4.

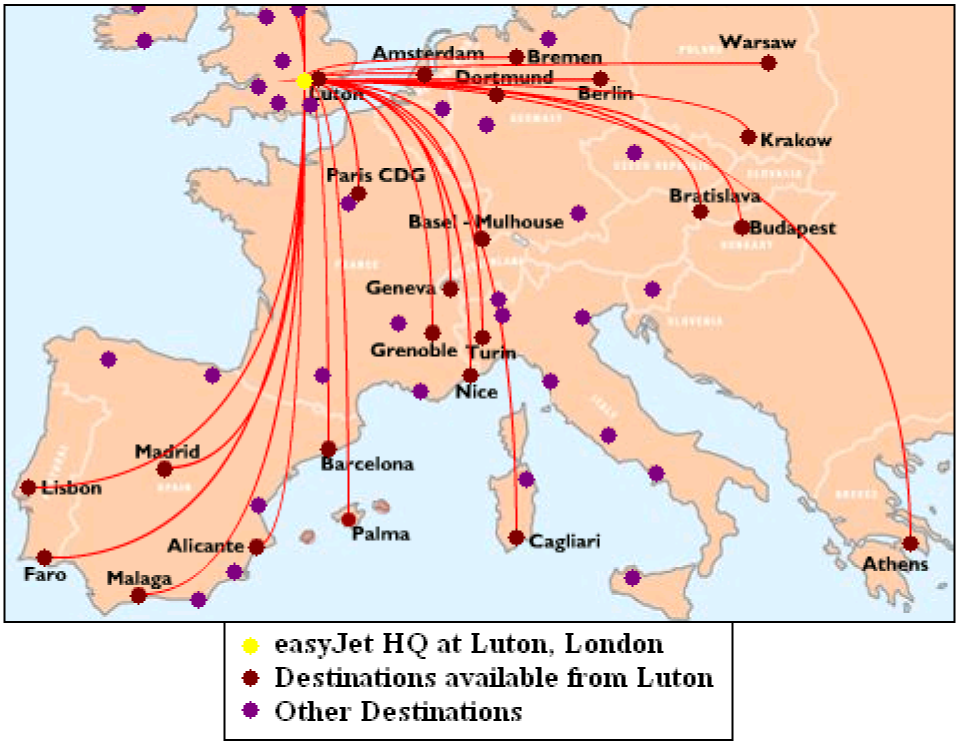


Figure 2-4: easyJet's Continental Destinations (adapted from easyJet, 2006)

An analysis of LCC market share reveals their success in focusing on tourist destinations. On routes from London to leisure destinations serving less than 1 million passengers per year, for instance, low-cost carriers have attained more than 50% of overall market share, at times even displacing major carriers from those destinations. However, this does not suggest that low-cost carriers have been unsuccessful on larger routes. To the contrary, they have captured up to 25% of traffic from London to major hubs and up to 50% of traffic from London to other major airports with traffic surpassing 1 million passengers per annum (Dennis, 2004).

<u>LCC and the Restructuring of Air Transport</u>

By no means are the airlines the only group affected by the success of low-cost carriers. Rather, the successful entrance of the low-cost carrier into the airline market has yielded significant effects across the aviation industry. Both airlines and airports have been subjected to changes resulting from an increasingly competitive market for their services. Travelers, on the other hand, have discovered new destinations and new means of arriving there.

Airlines

Most obvious among the effects of LCC entry is the increased competition faced by traditional carriers such as United and Delta in the United States or British Airways or Lufthansa in the European Union. By offering a differentiated aviation product at a lower cost, LCC have successfully lured leisure travelers and cost-conscious business travelers away from traditional carriers and charter airlines. This success appears to be leading to permanent structural changes in the airline industry, in part due to the response of the network carriers to increased competition.

Despite some anecdotal evidence that network carriers have attempted to oust low-cost carriers by increasing capacity on LCC routes, much of the competitive response has been focused on price-matching (Morrell, 2005). In other instances, competitive responses have manifested themselves in the creation of low-cost airlines within the structure of a network carrier, as in the unsuccessful case of Delta's Song in the United States and others in Europe. Whether these changes will result in overall efficiency increases and the creation of a new business model for large carriers remains unclear. However, there is evidence to suggest that a trend toward airline partnerships capable of combating LCC growth will permanently change the face of the airline industry. According to Mercer Management Consulting, one-third of national flag carriers and second-tier airlines may exit the passenger market in the coming years, leaving behind a consolidated group of major international carriers dominating business travel and two to three leading low-cost carriers with significant market share in the intra-European market (Mercer, 2002). Certainly, such changes would have important implications for airport-airline interaction, effectively changing the bargaining power of and relative economic strength of each.

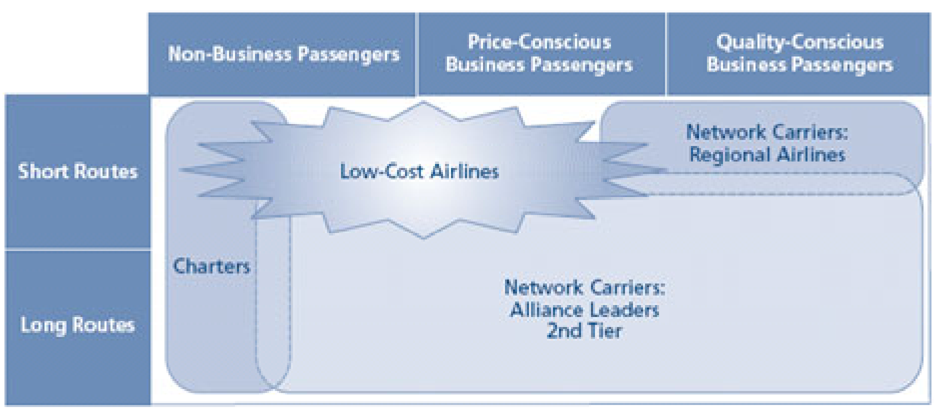


Figure 2-5: Projected Segmentation of European Aviation Market (Mercer, 2002)

Airports

Aside from demanding a very different airport product, low-cost carriers have effected important changes in the provision of airport services by avoiding the congestion and airline costs associated with large “legacy” airports such as London/Heathrow (LHR) in favor of smaller secondary or regional airports. In so doing, low-cost carriers have shaken the so-called “natural” monopolies formerly enjoyed by large airports and introduced previously unseen competitive forces into the provision of airport services.

Table 2-2: Example Airport Preferences of EU and US Low Cost Carriers (Informed by de Neufville, 2005)

Region	City	Primary Airport	Secondary Airport	LCC at 2nd Airport
EU	Berlin	Tegel (TXL)	Schonefeld (SXF)	Ryanair, easyJet, Brussels Airlines
EU	Frankfurt	Main (FRA)	Hahn (HHN)	Ryanair, Wizz Air
EU	London	Heathrow (LHR)	Stansted (STN)	Ryanair, easyJet, Sky Europe
			Luton (LTN)	easyJet, Monarch, Wizz Air
EU	Milan	Malpensa (MXP)	Bergamo (BGY)	Ryanair, Wizz Air
EU	Rome	Fiumicino (FCO)	Ciampino (CIA)	Ryanair, easyJet, Wizz Air
US	Miami/Fort Lauderdale	International (MIA)	International (FLL)	Southwest, , Air Tran
US	Chicago	O'Hare (ORD)	Midway (MDW)	Midway, Southwest Air Tran, ATA
US	Boston/New England	Logan (BOS)	Providence (PVD)	Southwest
			Manchester (MHT)	Southwest
US	Los Angeles	International (LAX)	Long Beach (LGB)	JetBlue
			Ontario (ONT)	ATA, JetBlue, Southwest
			Bob Hope (BUR)	JetBlue, Southwest
			John Wayne (JWA)	Southwest

Notes: Some low-cost carriers do choose to serve more congested airports for various reasons. For example, serves BOS, Air Tran BOS and DCA, and easyJet MXP.

In essence, airports can no longer depend on location alone to provide traffic; to the contrary, evidence suggests that low-cost customers are willing to bypass nearby airports in order to fly on a low-cost carrier (Dennis, 2004). LCC evolution, therefore, has contributed to a differentiation of airport products wherein closely-located airports compete to serve different customer markets, airlines, and routes. The London multi-airport system demonstrates this occurrence particularly well. Whereas Heathrow (LHR) focuses on international traffic, Luton (LTN) caters to holiday tours, Stansted (STN) attracts LCC, and London City (LCY) advertises to business travelers. As a result of this differentiation, secondary airports in the vicinity of major cities have experienced significant growth.

Passengers

In general, low-cost customers demand a different product than the business travelers which often supply the lion's share of airline revenue. Leisure travelers, for instance, do not require the flexible schedules demanded by their business counterparts, meaning that their service providers need not schedule as many flights throughout the day on any given route. In addition, they are less sensitive to increased travel times to airports or to reductions in airline services. Business passengers are not immune to the lure of the LCC, however. Indeed, low-cost carriers have challenged the position of many major carriers by attracting more flexible and cost-conscious businesspeople.

Meanwhile, passengers in general have benefited from lower ticket costs and, due to the increasing use of smaller, less congested airports, reduced waiting times and shorter walking distances within terminals. Despite suffering an increase in journey time from city centers, the overall growth in the number of passengers seems to imply that the benefits of LCC service outweigh this downside for many travelers.

Redefining Airport-Airline Interactions

In addition to increasing competition between airports, the introduction of the low-cost carrier has also affected the effective bargaining position of airports when dealing with their airline customers. Whereas airlines had previously been willing to acquiesce to airport demands in order to gain the use of airport services, evidence suggests that this dynamic is changing. Low cost carriers, due to their proven ability to attract traffic to an airport or region, have gained a particularly strong bargaining position and have managed to negotiate long-term contracts, joint marketing and risk sharing, and significantly reduced airport fees. In one case, the Belgian government offered to pay Ryanair to service its airport at Charleroi, rather than having Ryanair pay for airport services (Dennis, 2004)!

These changes are not limited to low-cost carriers, however. Rather, by increasing the number of useable airports in Europe and the Americas, low-cost carriers may be placing all airlines in a relatively stronger position by increasing their ability to switch between airports in the same region (Graham, 2004).

<u>Novel Demands on Airport Facilities</u>

Whereas previous subsections have focused on the generalized effects of low-cost carriers on airport siting and bargaining power, a great deal of evidence remains regarding the specific standards which LCC are demanding of airports. These have a

Table 2-3: Facilities Requirements of LCC and NC (Pitt, 2001)

Low-fare carrier	Network carrier
Access	
Location of secondary importance. Good road and rail links not essential but preferable.	Convenient location essential to service, particularly for non-economy passengers
Terminal	
Small ticketing area only (concentration on low cost sales over Internet)	High profile ticketing desk reflecting corporate image and presence
Fast check in preferred but quality of location is a secondary issue. Control of speed essential	Check in convenience and profile is of great importance
Terminal services (such as food etc.) of secondary importance	Important that passengers feel purchasing needs are met
Terminal facilities not important	Image of major international hub with good facilities preferable
Gate	
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 lounge facilities only	Business and first class lounges required in addition to economy space (separation of different classes essential to product)
Ability to separately route incoming and passengers preferable to save time	Long turn around times provide outgoing passengers ample time to route passengers in appropriate manner
General	
Minimal catering facilities required	Facilities for preparation of in flight food essential as forms part of package
Cleaning staff required less frequently. Minimal facilities requirement	Aircraft cleanliness essential part of package
No standby aircraft parking during daytime	Standby aircraft require parking
Efficient removal and loading of aircraft baggage and cargo	Efficient delivery of arriving baggage to customer a priority

particularly important effect on airport design. Given the trend of LCC development, successful airports must now be able to provide for both LCC and NC demands or be prepared to succeed while forfeiting the patronage of one of the two. This subsection highlights several key differences between LCC and NC demands and presents proactive measures which airport designers can take to promote LCC entry.

Non-Traditional Siting

The catchment area model, which posits that an airport's location relative to passengers within a region primarily drives airport traffic, has long been a standard in airport siting. Despite several studies disputing its usefulness (de Neufville, 2002), the catchment model has remained in use. However, low-cost carriers have provided a strong challenge to this thinking; airports serving low-cost carriers have shown the ability to attract passengers from well outside their traditionally defined catchment areas. Only 18% of passengers at Charleroi airport, for instance, derive from the airport's natural catchment area (Dennis, 2004). Similar data are available for airports throughout Europe, including at London/Stansted (STN), the United Kingdom's 3rd busiest airport (BAA, 2007).

Airport Ground Access

Perhaps even more so than with airports serving legacy carriers, those serving no-frills airlines require exceptional ground access. One study by Warnock-Smith and Potter, as a result, shows that airport accessibility is a leading factor in the airport choices of low-cost carriers (Warnock-Smith & Potter, 2005). This finding derives directly from the LCC passenger's willingness to travel longer distances in order to reduce trip costs and from the LCC predilection for secondary airports. Airports seeking to attract LCC, therefore, generally require inexpensive transportation modes with good access to areas lacking low-cost. This requirement need not call for expensive rail services; rather, simple road transit is often satisfactory (de Neufville, 2006).

These standards contrast with the model for larger airports with legacy patrons, several of which have developed much celebrated high speed, fixed-route access that has not provided a good investment return (de Neufville, 2006). Indeed, some high speed systems, by tending to focus more on city centers than on a larger region, are unlikely to serve low-cost carriers well. Rather, the costs of such a system, if passed on to the airport, airlines, and passengers, could deter LCC service.

Rapid Turn-Around Times

According to one survey of European low-cost airlines, the availability of convenient slots for take-off and landing and the ability to rapidly return a plane to flight are among the dominant airport requirements for low-cost carriers, second only to regional demand for low-cost service (Warnock-Smith & Potter, 2005). This requirement maximizes the productivity of aircraft, a primary factor in minimizing costs. Therefore, low-cost carriers have managed to increase the usefulness of their aircraft substantially (de Neufville, 2006) relative to their competitors. Maintaining such efficiency thus requires airports with the capacity to provide an uncongested airfield and airspace. By contrast, network carriers often prefer major hub airports such as the Frankfurt Main Airport City (FRA), where some 23.6% of flights are delayed with an average delay time of 37.2 minutes (AEA, 2007).

1st Quarter 2007	DEPARTURES								ARRIVALS	
	Delayed >15 minutes								Delayed > 15 minutes	
			REASON FOR DELAY							
AEA carriers at:	flights [%]	vs l.y.*	Load & Aircraft Handling Flight Ops	Maintenance/ Equipment failure	Airport & Air Traffic Control	Weather	Reactionary (late arrival)	minutes [avg]	flights [%]	minutes [avg]
London Heathrow	**30.1**	▲	7.4	1.4	9.9	0.9	10.6	32.9	29.6	36.6
Madrid	**25.3**	▼	2.6	3.6	8.0	0.2	10.8	39.6	31.2	38.3
Copenhagen	**24.6**	▼	5.6	4.8	3.3	1.3	9.6	41.7	25.7	43.9
Stockholm	**24.5**	▼	4.8	2.3	5.9	2.2	9.5	38.2	24.8	39.7
London Gatwick	**24.1**	▲	7.0	2.4	4.8	1.0	9.1	28.1	24.9	33.2
Frankfurt	**23.6**	▼	2.2	2.4	6.6	0.8	12.0	37.2	26.3	40.9
Geneva	**23.4**	=	2.2	0.8	7.0	1.3	12.5	39.0	24.5	34.9
Helsinki	**23.4**	▲	3.9	3.7	6.1	2.9	7.0	37.1	21.5	40.4
Paris CDG	**22.4**	▼	5.5	2.2	8.0	0.4	6.6	36.4	18.4	36.1
Rome	**22.1**	=	3.7	2.7	6.2	1.7	8.0	44.5	23.0	44.3
Zurich	**22.1**	=	1.5	1.0	6.6	1.8	11.1	36.8	22.9	38.7
Amsterdam	**22.0**	=	4.1	3.1	6.0	0.8	8.1	45.9	17.9	58.5
Dublin	**21.8**	=	2.6	1.5	6.8	0.9	10.0	41.5	28.8	36.5
Lisbon	**21.8**	▲	1.8	1.3	7.1	0.5	11.0	39.2	24.7	36.8
Manchester	**21.7**	=	2.8	2.0	5.3	1.0	10.7	45.8	21.7	41.4
Larnaca	**20.6**	=	3.9	4.6	3.0	0.2	9.5	62.8	35.9	54.6
Munich	**20.4**	▼	1.2	1.7	7.4	1.7	8.6	41.2	16.3	44.7
Oslo	**20.4**	▼	4.3	2.4	3.4	1.2	9.2	41.0	25.6	40.2
Milan Malpensa	**20.0**	▼	3.3	3.3	4.9	0.7	7.8	41.7	25.3	37.1
Barcelona	**19.3**	▼	2.7	1.4	7.6	0.2	7.7	39.6	18.9	39.3
Athens	**18.5**	▼	6.7	2.6	4.6	0.2	8.2	40.4	21.3	39.3
Istanbul	**17.3**	▼	2.2	0.5	10.1	0.7	3.8	40.0	26.9	42.4
Paris Orly	**16.6**	▼	2.9	1.2	4.7	0.4	7.4	42.8	25.3	37.3
Dusseldorf	**15.9**	▼	0.8	1.5	5.7	0.6	7.5	38.9	18.7	37.9
Brussels	**15.1**	▼	1.3	1.0	4.9	0.7	7.4	42.4	17.1	37.9
Milan Linate	**15.0**	▼	1.0	1.0	7.4	0.2	5.6	36.0	22.7	36.3
Vienna	**14.1**	▼	1.5	1.5	4.8	0.3	6.1	32.5	14.8	36.1

14 May 2007

* Compared to Q1 2006 results (vs l.y.): = unchanged, ▲ increase in delay rate (worsening), ▼ reduction in delay rate (improvement)

Figure 2-6: Delay Rates at Major European Airports (AEA, 2007)

Low Cost Services and Simple Passenger Facilities

In order to maintain the low ticket prices essential to their appeal, low-cost carriers are careful to select airports with low airport fees. In so doing, LCC encourage the sale of unbundled airport services; they often choose to purchase only the minimal number of services required and avoid expenses such as business lounges, retail services, air-bridges, and amenities. Further, low-cost carriers have proven adept at negotiating lower fees for aeronautical services.

The implication for airport planning is significant. Those airports serving low-cost carriers cannot expect LCC to provide the level of aeronautical revenues attained by hub airports. However, this need not impede success; Germany's Frankfurt/Hahn Airport (HHN), which abolished landing fees entirely for the Boeing 737 weight aircraft often operated by LCC (Francis, Fidato, & Humphreys, 2003), for instance, turned an operative profit for the first time in 2006 (HHN, 2007) after becoming a regional center for Ryanair.

Low cost airports also benefit from increased non-aeronautical revenues due to passenger demand for catering and shopping services not provided by the airline (Barrett, 2004). Airports hoping to serve low-cost passengers, therefore, must emphasize simple terminals, rapid check-in procedures, and functional catering facilities in order to both attract the low-cost customer and to provide time for the customer to purchase goods. In many cases, these principles contrast with the design of elaborate shopping areas, high-profile ticketing areas, business lounges, and transfer passenger facilities common at main airports, thereby exacerbating the design conflict for those wishing to serve both network and low-cost carriers.

Additional Capacity

Finally, European low-cost airlines emphasize the importance of additional airport capacity in determining their airport choice (Warnock-Smith & Potter, 2005). Given that the introduction of the low-cost carrier has been shown to result in massive increases in passenger traffic, airports wishing to service a low-cost carrier must be able to support that increase. Europe's Frankfurt/Hahn (HHN) provides a prime example. Hahn, a leading European low-cost airport, spent € 27 million on renovations before the arrival of Ryanair, which raised its passenger levels from 450,000 in 2001 to 1.5 million in 2002 (Gillen & Lall, 2004)[1].

This presents a particularly interesting problem for airport design, as unused spare capacity – which could easily result if an airport or its airline partners fail to achieve large traffic increases – can represent significant monetary waste. However, it appears that airports need only have the *flexibility* to grow in order to be successful, a prime point of this thesis. Baltimore's Washington International Airport (BWI), for instance, began its expansion soon after Southwest began servicing the airport. Since then, BWI's US $1.8 billion expansion and renovation program – which includes the creation of new concourses and the refurbishing of existing facilities in order to provide more parking, longer runways, and less terminal congestion – has attracted a second LCC, AirTran, and made BWI the region's second busiest airport (21 million passengers in 2006) ahead of regional giant Reagan International (DCA: 19 million passengers) and right behind Dulles International (IAD: 23 million passengers). Interestingly, BWI's competitor airport, Dulles, provides a second example, as it only recently surpassed BWI in traffic after itself acquiring low-cost service in 2004. Clearly then, low-cost carriers have shown a powerful ability to affect airport success.

4. Novel Uncertainties: Rise of the Multi-Airport Systems

Although the growth of the low cost carrier has clearly demonstrated its effect on air transport, LCCs are not alone in their ability to transform the airport industry. To the

[1] When placed in the context of today's billion dollar terminals, Hahn appears to have secured quite a deal!

contrary, the continued growth of multi-airport systems (MAS) has also added increasing uncertainty to airport management.

Certainly, MAS are not new. The Port Authority of New York and New Jersey, for instance, has operated three major airports – Kennedy (JFK), LaGuardia (LGA), and Newark Liberty (EWR) – since 1948 (Port Authority, 2006). Across the Atlantic, the London airport system has developed five *significant* airports under the control of BAA, including Heathrow (LHR) and Stansted (STN). However, the role and influence of multi-airport systems are growing rapidly with the development of LCC-driven secondary airports and the general increase in aviation demand. Moreover, many airports within the same region have not shown the level of cooperation enforced by joint management or ownership as in New York and London. To the contrary, MAS have fostered increased competition between airports in much the same way that LCCs have introduced new competitive forces to airlines. In effect, multi-airport systems – like low-cost carriers – are well on their way to becoming a permanent part of the air-transportation landscape, adding new uncertainties to which airport managers must adjust.

Where will traffic develop?	
	[1] Secondary airports create increased competition for traffic.
What will be the shape of the airport industry?	
	[1] Secondary airports are allowing for the creation of new route structures. [2] Secondary airports and LCC challenge hub-and-spoke arrangements.
How should airports be constructed?	
	[1] Competing airports yield increased differentiation. [2] Some airports are moving toward the “aerotropolis” idea; others are simplifying to better serve LCC.
Which customers should airports cater to?	
	[1] Increased airport differentiation allows for passenger segmentation. [2] Some large airports are attempting to integrate non-traveling customers into their revenue base by adding malls, offices, etc.

Figure 2-7: Multi-Airport Systems: New Questions, New Uncertainties

MAS Characteristics, History, and Growth

As defined by de Neufville and Odoni, multi-airport systems consist of the set of airports serving 1 million or more passengers per year (or 100,000 tons of freight) in a common metropolitan region (de Neufville & Odoni, 2003). This definition gives no emphasis to airport ownership or to political boundaries; to the contrary, experiential data show that these factors are unimportant from the perspective of the airport customer. Boston’s air travelers, for instance, choose between three airports in different states: Massachusetts’ Boston Logan (BOS), New Hampshire’s Manchester Boston Regional (MHT), and Rhode Island’s T.F. Green (PVD). In effect, the metropolitan region – the area that is accessible to the airport passenger – is more important than the city itself. The impetuses for this development have developed over time: while deregulation paved the way for airlines to choose new airports, increased passenger demand created the need for new capacity and low-cost carriers sought to reduce costs.

Demand Impetus

Due to the rapid growth in passenger traffic, the growth of MAS in the United States has been particularly pronounced. In cases where capacity at the main airport is limited, the use of secondary regional airports has come to provide a clear alternative. Bonnefoy and Hansman, for instance, demonstrated the importance of capacity constraints and delay rates at core airports (including Boston Logan) in the development of successful secondary facilities, especially in cases where some secondary "population basin" could be identified near the new airport (Bonnefoy & Hansman, 2004). de Neufville and Odoni, meanwhile, have noted that most airports handling over 14 million non-transfer passengers per year may have the capability to support secondary airports (de Neufville & Odoni, 2003).

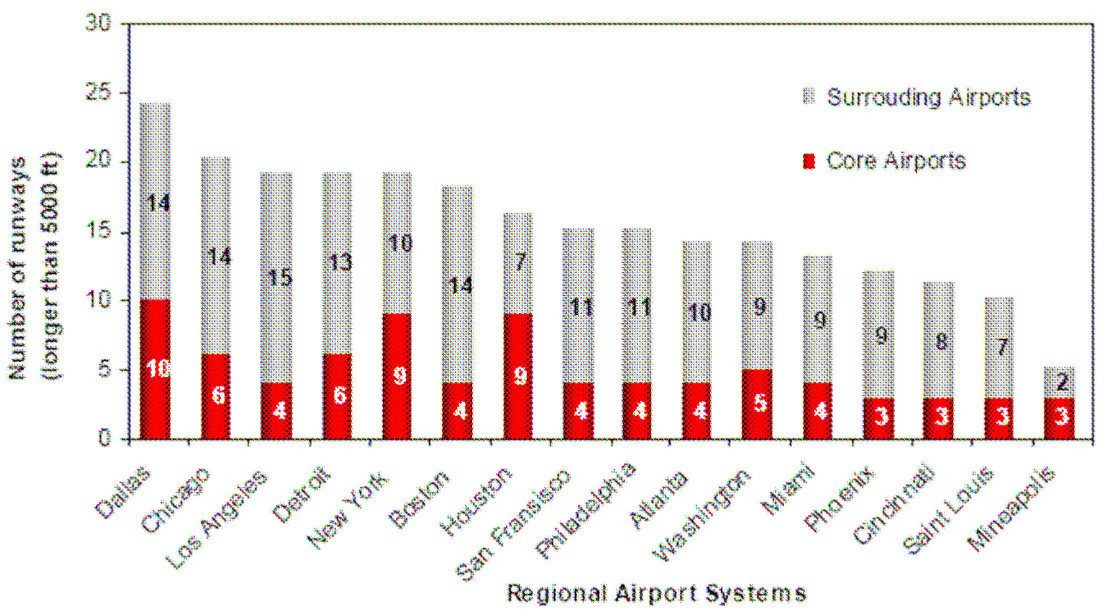


Figure 2-8: Availability of runways longer than 5000 ft at secondary airports in 16 US systems (Bonnefoy & Hansman, 2004)

Within this context, the creation of multi-airport systems can confer some important benefits. Airport competition aside, cooperation between system airports can defer losses to regional economies due to airport capacity constraints. Further, secondary airports can relieve congestion, as in the case of London, where Luton airport (LTN) has proven crucial to alleviating the effects of summer peaks in passenger travel at Heathrow (de Neufville, 1995b).

Other Impetus

Capacity constraints have not proven the sole factor in the creation of second airports. Rather, political and practical factors have also motivated multi-airport systems. In cases where the main airport is incapable of handling different types of traffic, for instance, new airports have been necessitated in the absence of threshold demand levels, as evidenced below.

Table 2-4: Multi-airport systems existing primarily due to political/technical reasons (Adapted from de Neufville & Odoni, 2003)

Metropolitan Region	Reason for System
Düsseldorf/Bonn	Political: former capital
Moscow	Political/military
St. Louis	Political: mid-American access point
Berlin	Political: result of divided city
São Paulo	Technical: runway length
Taipei	Technical: runway length
Buenos Aires	Technical: runway length
Rio de Janeiro	Technical: runway length
Belfast	Technical: runway length

Though perhaps not the primary reason for the development of multi-airport systems, MAS also carry other benefits. First, they increase passenger choice by allowing passengers to select from among multiple airports. Second, they allow for differentiation between airports in multi-airport regions, making competition and cooperation possible. The five airports within the London system, for instance, each tend to cater to different customer groups and differentiate their services to match.

The Role of LCC

As in other sectors of the air transportation industry, low-cost carriers have played an undeniable role in the development of multiple airport systems. In fact, research conducted within the United States names the entry of a low-cost carrier as the "essential stimulus" to the emergence of the secondary airports that form MAS (Bonnefoy & Hansman, 2004). As detailed in the section on low-cost carriers, the LCC predilection for secondary airports is clear: these facilities offer reduced congestion and lower cost while still providing access to key population centers. With this in mind, the growth of LCC and of MAS can be viewed as occurring in tandem, with each phenomenon fostering the growth of the other.

MAS and the Restructuring of Air Transport

Forecasting Difficulties

As a result of the symbiosis between MAS and LCC, then, both tend to be influencing the air transport industry in a similar pattern. As with LCC, for instance, the growth of the multi-airport system has added increased uncertainty to the practice of forecasting. Certainly, the development of multiple nearby airport facilities provides a significant challenge to the normal operation of the catchment area model. More importantly, though, secondary airports often defy predictions on traffic development despite attempts to relocate traffic as at Paris/Charles de Gaulle (CDG) or to close the core airport as at Osaka/Kansai International (KIX).

Further, the creation of secondary airports has been shown to increase the volatility of traffic for the entire airport system (Cohas, 1993). This volatility has been especially pronounced during the developmental phases of secondary airports; because these facilities generally have lesser amounts of traffic and are often served by fewer carriers, decisions made by a single airline can significantly affect traffic levels and profitability (de Neufville, 1995). According to de Neufville, such uncertainty can commonly last up to 20 years after the opening of the second airport (de Neufville, 1995b).

Table 2-5: MAS and Increased Traffic Volatility
(Cohas, 1993, as cited in de Neufville, 1995)

Multi-Airport System	Higher Traffic Volatility at Individual Airports (%)
New York	+ 10 %
San Francisco	+ 86 %
Washington/Baltimore	+ 127%

.

New Market Dynamics

Multi-airport systems, commensurate with LCC development, have also added to the development of new market dynamics within air transport. The development of niche airport markets is of particular interest as per its effects on airport design. This phenomenon is in no way limited to London, as mentioned above. Rather, airport differentiation is increasingly becoming a mark of increased competition. Whereas some facilities have sought to simplify and to cater to the LCC customer, others such as Amsterdam Schiphol (AMS) have moved towards creating aerotropoli, airport cities which go far beyond providing traditional airport services. The Schiphol Real Estate group, for instance, partakes in the commercial development of office complexes, hotels, shopping, and exhibition spaces under the airport name; Hong Kong International (HKG) includes one million square meters of retail, exhibition, business, hotel, and entertainment space near its passenger terminal (Airport Innovation, 2007).

Further, Graham suggests that a new MAS-enhanced atmosphere of competition and cooperation may eventually affect the relative bargaining powers of airport and airlines, as demonstrated in some limited cases. Already, some horizontal and vertical integration has been observed: BAA operates a rail link to LHR, the Heathrow Express; Cardiff International (CWL) operates its own travel agency; the Schiphol and Fraport airport groups have formed the Panatares alliance; and in an extreme case, airport company PlaneStation acquired the LCC EUjet to provide for its operations[2] (Graham, 2004). The growth of any of these trends could each signal significant changes in the aviation industry and carry unknown uncertainties. In most cases, however, changes to the traditional relationship between airports and airlines within the MAS/LCC environment has been more timid, marked instead by increased cooperation and negotiation.

Novel Demands on Airport Facilities

Finally, the development of multi-airport systems appear to be exerting influence on the design of airports themselves, an issue of particular important to airport planners. In most cases, these changes are in line with those influences exerted by low-cost carriers, a common patron of secondary airports. Perhaps the most pronounced difference, however, lies in the necessity of superior airport access. In the case of Baltimore/Washington (BWI) for example, the airport has developed train service to the DC area in order to better compete with the two major airports already in the region, Dulles (IAD) and Reagan (DCA).

5. Handling Uncertainty: Other Methods

Even without the influence of new trends in the aviation industry, several observers had already noted potent flaws in the master planning process. The introduction of low-cost carriers and the correlated growth of multi-airport systems have only heightened the difficulties. Given the increased influence of uncertainty, master planning must be augmented. The following subsections describe various proposals meant to help airport planners achieve success.

An Evolution of Planning

Over time, several different techniques have been introduced in order to improve planning practice. Though perhaps not specifically aimed at airports and transportation systems, each has been an attempt to avoid the flaws associated with dealing with overly idealized forms, as in master planning. Some of the most notable techniques include Simon's organizational approach (Simon, 1955), which integrates elements of psychology; Lindblom's incremental approach (Lindblom, 1959), which attempts to reduce the burden of fact-gathering by emphasizing the human predilection for steady change; and Etzioni's mixed scanning approach (Etzioni, 1967), an effort to avoid the conservatism inherent in incrementalism through employing a two-stage evaluation strategy[3]. Over time, however, each has waned in popularity.

---

[2] This experiment in integration failed with PlaneStation's loss of bank support in July, 2005.
[3] All planning references (Simon, Lindblom, and Etzioni) are as cited in Dempsey, 1997.

Strategic & System Planning

Strategic and system planning approaches, however, have enjoyed greater popularity. In contrast to master planning, strategic planning aims to be more proactive in creating effective designs. System planning, meanwhile, attempts to account for the wide variety of factors which affect projects by emphasizing the importance of the project's relationships with the wider world. Together, strategic and system planning create a paradigm of holistic thinking meant to identify levers for creating success. In order to facilitate this goal, strategic system planning focuses on the evaluation of various "what-if" scenarios which describe possible future events.

Despite having gained support from major organizations, traditional strategic and system planning has nonetheless lost some of its appeal within the aviation community. Even Michael Porter[4], a prominent founder of the technique, noted that strategic planning had not necessarily led to strategic thinking (as cited by de Neufville, 2003). Rather, the consideration of multiple scenarios and the evaluation of numerous levers within a highly complex system often resulted in a large and expensive planning process. Moreover, airport strategic planning often proved unidirectional; early errors in describing the overall system tended to propagate downstream in much the same way as in master planning (Caves & Gosling, 1999).

Even though the system of strategic planning for airports remains under review – Caves and Gosling present a re-evaluation in their 1999 book *Strategic Airport Planning* – it would therefore appear that airport planning techniques can still bear improvement. The benefits of strategic system planning aside, its unidirectional attempt to describe a complex world weaken its appeal in dealing with the increasingly uncertain world of air transport.

Real Options

Real options planning, while not in any way diminishing the benefits of being proactive (strategic) or system-oriented, has come to provide an increasingly popular alternative. In contrast to master planning and its substitutes, real options thinking does not emphasize the use of fixed forecasts or of complex system mapping. Rather, it uses a number of techniques to minimize the risks associated with uncertainty. The paradigm is simple. In real options planning, designers do not settle on a single most-likely forecast or scenario; instead, they seek to maintain the flexibility to adapt, regardless of what the future brings.

6. Wrapping Up: A review

A significant amount of experiential history has revealed that transportation projects are subject to a multitude of uncertainties. Variations in demand, economics, politics, and

[4] For more on Porter's techniques, please see Porter & Montgomery, 1991.

public opinion each constrain the ability of planners to successfully design for future needs. In an ideal world, planners could isolate and predict the effect of these uncertainties. However, the real world is not so forgiving. Instead, attempts to predict future states have led to the simple conclusion that the forecast is always wrong.

The air transportation industry is far from immune to these difficulties. Indeed, several iterations of airport planning methods have struggled to account for uncertainty. New trends in air transport do not signal relief. To the contrary, the growth of low-cost carriers and of multi-airport systems raises new, unanswerable questions about the future. Within this context, real options planning can provide a useful alternative to other planning techniques. By avoiding forecasts and promoting flexibility, the real options paradigm promises to reduce risk and to help promote success. These real options strategies will be explored in Chapter 3 and provide the basis for this thesis.

CHAPTER 3: REAL OPTIONS THEORY

Chapter 3 – Introduces the reader to the basics of real options theory, including its logical antecedents in finance, major concepts, and mathematical valuation methods.

Dealing with uncertainty presents a common challenge for the designers of long-term engineering systems. In contrast to short-lived projects, enduring engineering structures suffer increased difficulties due to greater complexity in predicting future specifications and in designing to future needs. As a result, systems designers must attempt to plan for unforeseeable circumstances such as changing functional requirements, novel technological developments, evolving load patterns, and new regulations that can create demands which conflict with initial designs and threaten obsolescence or financial failure.

The creation of a toll highway provides a simple example. Assuming that a highway is constructed to connect two major cities, several possible failures external to the engineering success of the design are possible. Given that "the forecast is always wrong," incorrect demand forecasts may lead to the creation of too many (or too few) lanes, resulting in financial losses. Otherwise, the introduction of new technologies such as an inexpensive rail connection between the two cities or of regional economic changes can create unexpected demand shocks to which the highway, even if designed exactly to specifications, simply cannot adjust. Another example, the development of airport systems, supplies a more complex archetype of long-term engineering projects; changes in aircraft, airline, economy, passenger type, and local competition can each create considerable adjustment challenges.

Ensuring that such adjustments are possible gives primary rationale to real options thinking. Real options, as termed by MIT Professor Stewart Myers (Coy, 1999), provide the right, but not the obligation to take actions which can help maintain or even increase the value of an engineering project despite uncertainty. This section presents the evolution and thinking behind real options theory. It further provides an overview of several analytical tools which can be useful in applying real options theory to the development of actual engineering projects.

1. Real Options: Theory and Evolution

In 1983, current Chairman of the US Federal Reserve Ben Bernanke argued that the presence of uncertainty can increase the value of delaying a financial investment (Bernanke, 1983). In so doing, Bernanke examined investments subject to two simple assumptions. The first assumption, irreversibility, posited that some investment decisions cannot be undone or substantially changed without incurring great or sometimes prohibitive costs. The second assumption held that decision-makers do not often have all the information relevant to making an irreversible decision although that information may become available in the future. Armed with these two assumptions, Bernanke concluded that postponing a commitment, while maintaining the ability to commit at a later time, can sometimes prove desirable by allowing an investor to make choices only after important information is revealed.

This conclusion lends credence to the primary thesis of options theory. In essence, Bernanke maintained that the right (option) to make a decision in the future has inherent value. The toll highway analogy again proves useful. Clearly, constructing unnecessary lanes is an irreversible process; the cost of removing additional lanes is likely prohibitive. Further, information regarding future economic conditions and the probability of a rail connection would certainly influence designers by giving a truer picture of highway traffic. Empirically then, what Bernanke proved true for financial systems also holds in engineering systems; options theory as it was developed for the financial markets can carry benefits in the physical world.

Financial Options to Real Options

The concept of "real options," wherein options theory is applied to physical objects, developed out of financial options theory, the primary subject of Bernanke's argument. Within the financial realm, purchasing an option gives investors the right to acquire (call) or divest from (put) a particular stock at a time determined based on the option type. As such, financial options provide a powerful tool for deferring irreversible investment decisions and managing uncertainty. Indeed, the success of options within the financial realm led to the extension of the theory into the physical world of engineering, hence the "real option."

Unlike financial options, real options regard a physical structure or system, such as the toll highway described earlier. However, the role of the option is the same; real options, like financial options, allow investors the opportunity to purchase the right to delay expensive or irreversible decisions. They therefore recognize the role that active management can play in either minimizing the damage from or taking advantage of an uncertain future (de Neufville & Neely, 2001). This concept has received increasing potency due to the work of several authors (McDonald and Siegel, 1986; de Neufville, 2006) and the promotion of the concept at universities such as MIT. More recently, the United States Office of Management and Budget recognized the usefulness of real options formulations, noting the effectiveness of real options thinking in situations where the costs of incorrect action outweigh the benefits of rapid action, as they often do when constructing long-term engineering systems. As such, the Office concluded as follows:

> 'Real options' methods have … formalized the valuation of the added flexibility inherent in delaying a decision. As long as taking time will lower uncertainty, either passively or actively through an investment in information gathering, and some costs are irreversible, such as the potential costs of a sunken investment, a benefit can be assigned to the option to delay a decision. That benefit should be considered a cost of taking immediate action versus the alternative of delaying that action pending more information. However, the burdens of delay—including any harm to public health, safety, and the environment—need to be analyzed carefully (US Office of Management and Budget, 2003, p.39).

Real Options "on" a System

Just as one may differentiate between real and financial options, one may also distinguish between two types of real options, namely real options "on" and "in" a system (Wang & de Neufville, 2006). This differentiation aptly separates real options in terms of identification, value determination, and complexity.

Real options "on" a system closely mirror financial options in terms of use (Mittal, 2004). In many ways, they provide a direct analog of financial options. Referring back to the example of a toll highway, a real option "on" the system would allow investors to either acquire or sell the highway at a given time based on its financial performance up to that date. In this case, the value of the option is fairly simple to determine, being a function of the money saved (or gained) after selling (or acquiring) the highway. One possible analog within the realm of airport development is the practice of landbanking, wherein investors seeking to develop a future airport acquire the land required well before making the decision to build the airport. In this scenario, the decision is not irreversible; the land can be sold or used to develop non-aviation products. However, landbanking helps to ensure that an airport *can be built* in the future and likely helps to lock in a lower cost. To further the analogy, landbanking could also ensure that a current airport could be expanded as necessary.

This description reveals three primary maneuvers common to real options "on" a system:

1. The right to acquire (buy) engineering systems.
2. The right to divest (sell) engineering systems.
3. The right to expand the size of engineering systems.
4. The right to contract the size of engineering systems.

Each of these maneuvers, though different, provide the option owner with the ability to defer important investment decisions until the information required becomes available, therefore helping to protect against uncertainty.

Real Options "in" a System

In contrast to real options "on" a system, real options "in" a system are far more diverse, complex, and more difficult to identify and appraise. These options cannot be applied to a system without consideration of the system's internal workings; rather, real options "in" a system derive from the system's design and therefore require an appropriate level of engineering knowledge. Moreover, the decision to implement a real option will likely affect and be affected by other design decisions and exhibit path-dependency.

The 25 de Abril Bridge, which spans the Tagus River outside of Lisbon, gives one example of the successful application of real options "in" a system (Gesner & Jardim, 1998). Completed in 1966, the Tagus River Bridge was constructed as a four-lane roadway that could be retrofitted to in order to support both a highway and a railroad. As a result, bridge designers made *engineering decisions* internal to the bridge design which allowed for future retrofits. These decisions paid off in 1992 after the region's population and economic growth caused bridge traffic to exceed the original expectations. Whereas other cases may have led to the total reconstruction of the bridge, engineers were able to widen the roadway deck to six lanes and to install a railroad deck without causing major disruptions to bridge traffic. As such, the Tagus River example demonstrates the usefulness of delaying a decision (whether or not to build more road or rail lanes) by designing an engineering structure which provides for future eventualities. Had the designers chosen to build a six-highway bridge with railroad capabilities in 1966, the Tagus River Bridge would have remained underused for over 25 years. However, had the designers chosen not to allow for future expansion, the bridge would have remained over capacity or required great financial losses to expand. Rather, the decision to combat uncertainty by designing flexibility into the system allowed for the bridge to be expanded only when necessary at minimum cost.

2. Appraising Real Options: Square One

As with all financial mechanisms, the usefulness of a real option correlates with calculations of its costs and expected benefits. This section and its successors introduce common evaluative methods for financial options and contrast them with techniques used in engineering practice. Finally, the chapter ends by revealing approaches which allow for real options – options with importance to engineering – to be appraised while accounting for uncertainty.

Financial Options Valuation

The chief assessment methodology for appraising financial options, known as Black-Scholes formula, led to a Nobel Prize for creators Myron Scholes and Robert Merton in 1997[5]. Computation through Black-Scholes assumes that options can be valued by envisioning them as a portfolio of assets and loans which can be bought and sold in a free market. The value of the option, then, equals the portfolio's market, given that there are no opportunities for arbitrage profits.

Although this methodology was developed specifically for financial options, it does not however translate well for the financial evaluation of all real options. Whereas financial options such as the ability to obtain or reject a stock at a given time are easily converted into an equivalent set of tradable assets and loans, this is often not the case in engineering systems. Rather, physical limitations restrain the ability of a particular material item – an additional highway lane or airport runway, for example – to be replicated and sold freely.

3. Appraising Real Options: Square Two

Stakeholders involved in the construction of large projects have several methodologies for selecting investments, most of which are quite different from those used for valuing

[5] Fischer Black was ineligible for the Nobel Prize as a result of his death.

financial options. In general, these techniques allow investors to rank the desirability of different ventures based on costs and expected profits. Traditionally, several of these approaches share a common failing – an inability to account for uncertainty.

Net Present Value

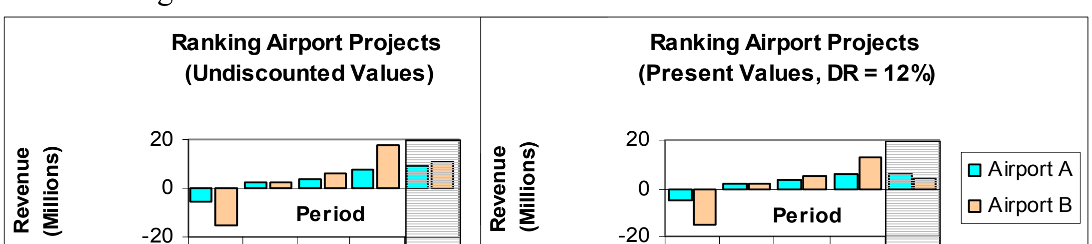
The calculation of a net present value (NPV) remains one of the most common methods for evaluating the financial worth of a particular investment. By resolving the worth of each project into a single monetary value, the net present value (alternatively, discounted cash flow) method allows for a simple ranking of different alternatives; more favorable projects have a higher NPV than less favorable ones.

Though simple, net present value calculations are quite powerful, as they reflect the relationship between the value of money invested and the time at which the investment is made. This concept, the "time value of money," results from the financial notion that money today (or yesterday) carries greater value than money tomorrow (or today). This is not the result of inflation alone; rather, present money is worth more than future money because of the value which can be obtained from today's investments. Since different groups tend to profit from investment at different rates, all net present value calculations therefore depend on determining a 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. Upon determining the discount rate, the method can then be applied using Equation 3-1 which requires the discount rate per period (r), the number of periods (n), and the revenue in each period (F_n).

Equation 3-1: Net Present Value Calculation

$$NPV = \sum_{t=0}^{n} \frac{F_n}{(1+r)^n}$$

Figure 3-1 provides an example wherein an investor compares two airport projects over three periods. Airport B, though significantly more expensive than Airport A, grows in revenue at a greater rate.



	0	1	2	3	Total
Airport A	-5	2	4	8	9
Airport B	-15	2	6	18	11

	0	1	2	3	Total
Airport A	-5	2	3	6	6
Airport B	-15	2	5	13	4

Figure 3-1: 2-Stage Evolution of Stock Prices

Simply summing the revenues in each period – in effect, applying a discount rate of 0% per period – provides an incorrect project ranking, implying that the faster growing Airport B is more profitable over three periods. However, applying a discount rate of 12% more accurately represents the time value of money and shows that Airport A is in fact the superior investment.

The airport example further reveals a key concern relevant to the use of net present value rankings; all results are highly dependent on the discount rate, for which no definitive means of determination exists. As such, low discount rates tend to favor projects with higher initial capital investments. In the airport example, for instance, a discount rate of 6% suggests that Airport B – the more capital intensive options – is the more favorable.

Net present value carries other flaws which render it inappropriate for the evaluation of flexibility if used on its own. Since the determination of revenues during each period generally relies on fixed forecasts, net present value neither incorporates uncertainty nor does it recognize the benefits of flexibility over the long term. To the contrary, net present value calculations tend to diminish benefits acquired due to flexibility over the course of long-term investments. Later sections of this chapter address this problem.

Internal Rate of Return

Evaluating projects based on an internal rate of return avoids the complication of choosing a project-specific discount rate. Rather, the internal rate of return is defined as the discount rate which makes the net present value zero. Though also a common measure, internal rate of return suffers from most of the same difficulties as NPV evaluation; neither uncertainty nor flexibility may be easily accounted for.

Benefit Cost Approach

The benefit cost approach (BCA) represents a popular mechanism for determining the value of large government projects such as airports and railroads, hence its relevance to this thesis. In addition, BCA – unlike traditional NPV calculations – allows for a fairer ranking of projects of different sizes. Quite simple in execution, cost-benefit analysis (as it is alternatively called) categorizes projects on the basis of Equation 3-2. Favorable projects carry a ratio greater than 1; that ratio increases with the project's desirability.

Equation 3-2: Benefit-Cost Calculation

$$\boxed{BCA = \frac{\sum Benefits}{\sum Costs}}$$

As in the net present value approach, both benefits and costs are discounted, meaning that the analysis is subject to errors in choice of discount rate. Further weaknesses of the method include inconsistent definitions of benefits and costs and a natural bias against high operating costs. For this reason, many financial institutions tend to avoid the measure (de Neufville, 1990a).

4. Appraising Real Options: Square Three

As with all investments in financial options and traditional engineering projects, decisions regarding the implementation of flexibility require knowledge of expected costs and benefits. However, ranking flexible (and inflexible) alternatives is fundamentally different from ranking other types of ventures. First, evaluating flexible options requires comparing variations on the same project rather than comparing entirely different projects. Second, the evaluation must account both for uncertainty and for the ability to adapt to new conditions. This section presents a series of different approaches suited to financial evaluation while focusing on those methods most applicable to assessing real options.

Accounting for Uncertainty

Flaw of Averages

In one common, intuitive means of accounting for uncertainty, variations in an uncertain variable may be tackled by considering the average value of that variable over time. Therefore an investor can consider an airport which serves no passengers in year 1, 2 million passengers in year 2, and 10 million passengers in year three to have an average throughput of 4 million passengers per year. The flaw in this thinking is evident; the airport, if constructed to suit its average traffic, remains underused for the first two years and severely overcapacity in the third. Stanford University's Sam Savage explored the dangers of this type of assessment, the "flaw of averages," in a 2000 article, arguing that "plans based on the assumption that average conditions will occur are usually wrong (Savage, 2000)."

In other words, using average values to account for uncertainty often leads to suboptimal results. Mathematically, Jensen's inequality expresses this concept. A convex function of a variable's expected value does not equal the expected value of that function.

Equation 3-3: Jensen's Inequality

$$\boxed{F(EV(x) \neq EV(F(x))}$$

Clearly, the use of average values for uncertain parameters does not provide a satisfactory means of valuing options or of ranking flexible alternatives.

Value at Risk and at Gain

Conversely, the value at risk and gain (VaRG) concept provides a useful analytical method for including uncertainty into financial evaluations. By emphasizing the reality that an investor can only foresee the actual value of any particular project probabilistically, VaRG calculations stress the role of uncertainty in design. By definition, VaRG assigns a confidence level (90% certainty) to an investor's expected maximum loss or minimum gain. Viewing the value at risk for a particular project as a cumulative distribution function, the value of flexibility becomes clear. A well designed flexible alternative can decrease a project's maximum loss (or increase its minimum gain) for a particular confidence level.

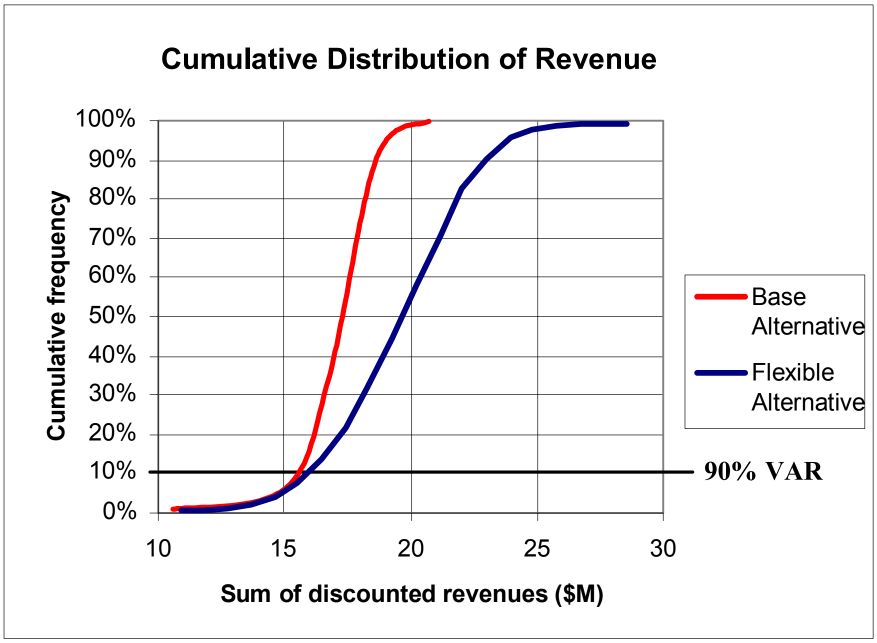


Figure 3-2: VARG Illustration

Valuing Flexibility in Physical Systems

Binomial Lattice Model

In 1979, Cox, Ross, and Rubinstein presented the binomial options pricing model as a mathematically accessible alternative to the Merton/Scholes approach (Cox, Ross, & Rubinstein, 1979). Though intended as a means of simulating uncertain fluctuations in stock prices, the model has proven useful in the valuation of real options, subject to important conditions.

The strength of the binomial lattice lies in its ability to reduce a large set of future possibilities to a manageable size. Within the context of markets and financial options, one may consider the evolution of stock prices. In general, the price of a given stock undergoes a random evolution. Even if it were assumed that the stock price only increased or decreased in value by a fixed amount during each period, the number of possible outcomes would grow exponentially (2^n) with the number of periods (n). Therefore, if each period represented one day, an investor attempting to determine a stock price on the 20 days in the future would have over 1 million possibilities (2^{20} states) to consider.

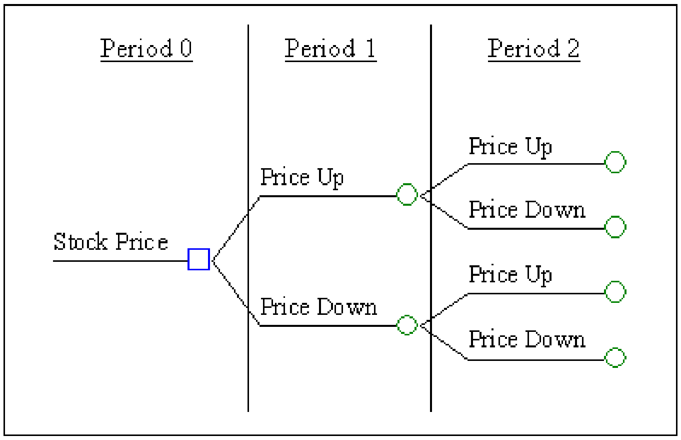


Figure 3-3: 2-Stage Evolution of Stock Prices

The binomial lattice model simplifies the investor's dilemma significantly. Given the parameters of the Cox-Rubenstein structure, the stock price is assumed to either increase by a fixed factor (u) or decrease by a different, fixed factor ($d = u^{-1}$) during each period. This condition forces the lattice to recombine: an upward followed by a downward motion is equal to a downward followed by an upward motion. Since the number of possible states now increases linearly with period (n), the investor must consider only 21 possibilities on the 20th day. Figure 3-4 illustrates.

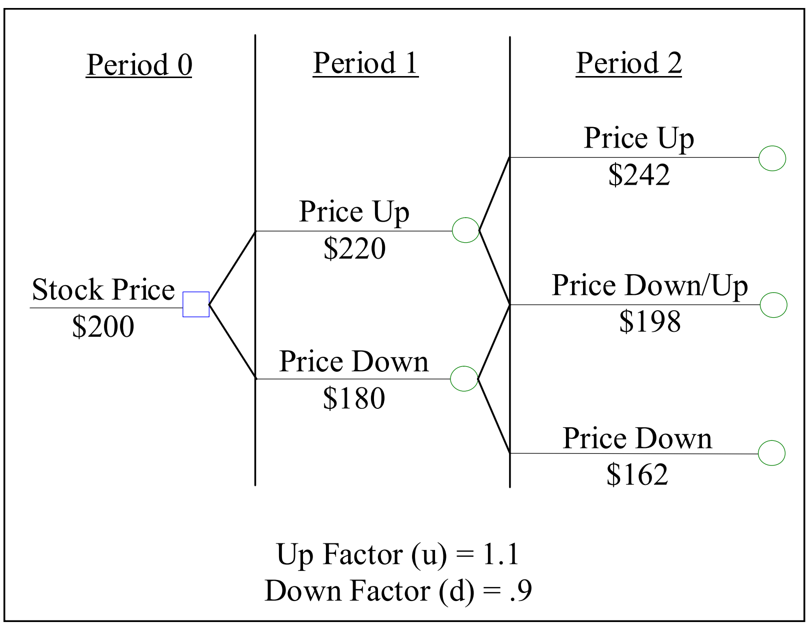


Figure 3-4: Binomial 2-Stage Evolution of Stock Prices

Further, binomial lattices allow the user to determine probabilities for each state, as in Figure 3-5, which continues the stock price example.

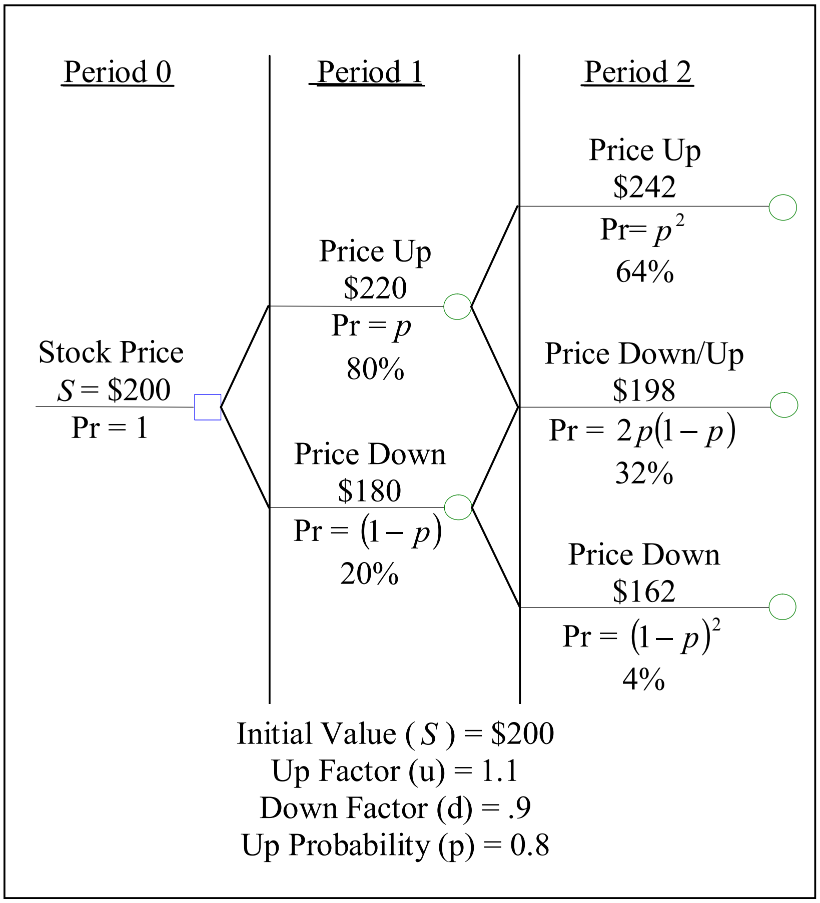


Figure 3-5: Binomial 2-Stage Evolution of Probabilities

Although the evolution of stock prices may not necessarily be important for any physical engineering system, the binomial lattice model itself can prove helpful to engineers and designers. For instance, an airport planner could employ the lattice structure to model the development of traffic at a given airport over several decades. This provides distinct advantages; unlike in conventional master planning methods where airports are designed to best fit one – or very few – possible future traffic outcomes, use of the lattice method allows stakeholders to view and best account for numerous uncertain possibilities with relative ease.

Successful use of the binomial lattice requires satisfying three key assumptions which should be considered in modeling physical systems. First, the user must have access to sufficient past data with which to calculate viable values for the multiplicative factors (u and d) and associated probabilities (p). Further, the user must have knowledge of the initial state (S), which, in the airport example, is the starting demand for air transportation. Equation 3-4 links the calculation of these variables to the length of each period (Δt), the average growth rate as a percentage of starting value (v), and the standard deviation (σ) of the data as a percentage of starting value (S).

Equation 3-4: Calculation of Parameters for Binomial Lattices

$$u = e^{\sigma\sqrt{\Delta t}}$$
$$d = e^{-\sigma\sqrt{\Delta t}}$$
$$p = .5 + .5\left(\frac{v}{\sigma}\right)\sqrt{\Delta t}$$

Second, the binomial model assumes the non-negativity of values modeled. In economic (stock prices) and real (passenger traffic) systems, this requirement does not impose important restrictions.

Third, the binomial model requires that the evolution of states is path-independent; therefore, all paths to a particular state (defined by period and value) are equal in result. In the stock price example, this implies that arriving at a stock price of $198 in Period 2 through Price up first and Price down second does not differ from arriving at the same stock price through Price down first and Price up second. This condition, though perhaps well suited to financial markets, holds important ramifications in engineering systems. Indeed, the level of traffic at an airport in Period 1 may affect decisions on expanding/contracting airport size, which would in turn affect airport traffic in Period 2. Despite the usefulness of the binomial lattice in modeling certain physical systems, then, the condition of path-independence can prove severely limiting, as explored further in Chapter 5.

Decision Tree Analysis

Decision tree analysis provides a useful, graphical means of representing the effects of uncertain events. Further, it allows planners to account for managerial flexibility, the ability to make real-time decisions regarding system development (de Neufville, 1990a). By integrating these elements, decision trees provide a powerful tool for determining best choices under uncertainty.

This methodology permits multiple advantages over the binomial model. Foremost among these, decision tree analysis does not assume path dependence and therefore allows planners to consider the effects of real world changes (i.e. expanding an airport). Further, it frees analysts to consider the impact of entirely different uncertain events without subjecting the model to limiting parameters such as an average growth rate or a predetermined evolution of probabilities. Conversely, decision trees can quickly develop into “messy bushes;” modeling a large number of chance outcomes and future decisions can quickly overwhelm computational power. In addition, the accuracy of a decision tree largely depends on the ability of the user to correctly structure all chance outcomes, future decisions, their probabilities and their costs.

Figure 3-6 expands the stock example from above for use in a decision tree. In this version, the investor faces the question of whether or not to buy a stock (Stock A) for $200.

Proper decision tree analysis requires that the investor, moving backwards through the tree, execute decisions in order to maximize expected value. Therefore, if the stock price increased in Period I, the savvy investor would choose to keep Stock A because the expected value of keeping the stock ($222.40) is greater than the expected value of selling it ($220). Conversely, the same investor would choose to sell the stock if its price had declined during Period I. Regardless of the chance outcome in Period I, the investor would choose to buy the stock since the expected value of purchasing it ($213.92), given value-maximizing decisions in Period II, is greater than the expected value of not doing so ($200).

Chapter 5 explores an analog of this example within the engineering world; the choices to buy and keep stock are replaced by alternatives regarding how best to construct and expand an airport structure. Indeed, decision tree modeling proves rather well suited to considering complex transportation systems in which numerous outside factors can cause step changes in demand and profitability.

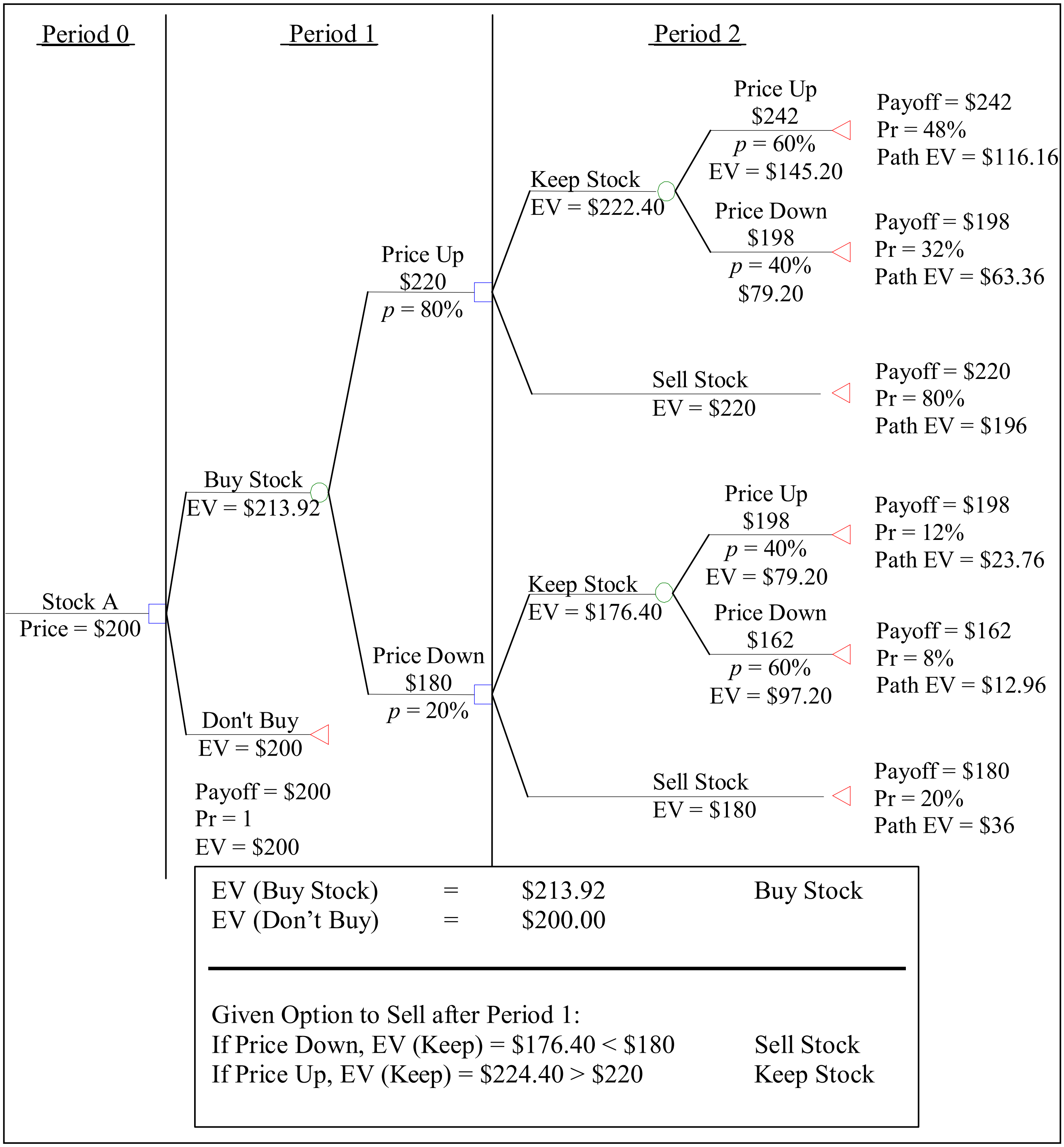


Figure 3-6: Stock Buy/Sell Decision Tree

CHAPTER 4: AIRPORT FLEXIBLE DESIGN STRATEGIES

Chapter 4 – Provides airport specific real options concepts as best applied by particular stakeholders. As such, it includes a stakeholder analysis of major players on the international, national/regional, and local/airport levels.

Airport decision-making occurs at multiple levels. Through a combination of rulemaking authority and funding support, international, regional, and national authorities – in combination with airport owners, designers, and managers – each contribute to different facets of airport design. Together, these groups add specifications through a step-wise and path-dependent process. Airport financing tells part of the story; because airports often confer important economic benefits to their home regions, numerous government agencies can become involved. Munich/Franz Josef Strauss Airport (MUC), for example, was funded not only by the German national government (23% share), but also by the city of Munich (26% share) and the Free State of Bavaria (51% share) (Dempsey, 2000). At similar airports worldwide, private investors and even international bodies such as the European Union also contribute significant funds and, in so doing, gain the right to set requirements on airport design and operations. Though the context and detail of these requirements may differ depending on the decision-maker, this section's central argument hinges on the idea that airport stakeholders share a common challenge – dealing with uncertainty – and a collective solution: flexible, real options based design.

However, it does not stand to reason that the same real options concepts are applicable to each stakeholder. To the contrary, airport stakeholders each have different goals and powers. Therefore, in order for the flexibility concept to be successfully integrated into airport design, real options solutions must be tailored to the individual desires and responsibilities of major stakeholders. Specific solutions must be addressed to each major stakeholder. This chapter attempts to coordinate various real options methodologies with international, regional/national, and airport level organizations of influence. Three groups are given special consideration: international bodies hoping to promote a safe and efficient global network, national and regional authorities developing vital transport systems, and airport designers and investors seeking to ensure profitability. Suggestions for applying real options concepts to each progress from simple solutions such as amending airport planning documents to more complex structural fixes; real-world examples taken from various airports are provided as necessary.

1. A Recap: Why Flexible Airports?

This chapter – not to mention the entire thesis – rests upon the contention that airports can benefit from the increased flexibility facilitated by real options thinking. The contention can be quickly defended. In 1983, Ben Bernanke[6] argued that systems which met two criteria – choice irreversibility and the need for information on unknowable future events – often benefit from the ability to defer decisions, a central theme of real

---

[6] A former MIT student and visiting Professor, Ben S. Bernanke currently serves as the Chairman of the United States Federal Reserve.

options design. Airports clearly fit the bill. Despite dissimilarities in the scope of choices available at the international, national/regional, and local levels, decisions in each sector exhibit irreversibility. Both the political and financial capital required and the size and detail of an airport construction project make it unlikely that decisions can be reversed or altered once an airport location has been chosen, design approved, or facility completed. Also true, the evaluation of alternatives at each level generally requires assumptions about future scenarios and therefore hinges on information not yet available. Just as changing capacity demands, regional economic health, and traveler requirements may alter a national preference for air transport, new technologies, novel aviation trends, and shifting airline configurations present volatilities which can affect the basics of airport planning. As a result, airport decision making can consistently benefit from deferring decisions and maintaining multiple alternatives for development. In short, real options thinking can create value at every level of the airport creation process.

2. The International Community

Several international organizations act in concert to affect the design and operation of the world's airports. Among these, the International Civil Aviation Organization (ICAO), International Air Transport Association (IATA), Air Transport Action Group (ATAG), and Airports Council International (ACI) each strive to represent the needs of different airport stakeholders and to define airport best practices. Together, they also work to promote the common goals of airport safety and security, efficiency, and fair competition. As such, although international actors are not necessarily involved in planning the minute physical details of the airports with which they are associated, they nonetheless can have important effects on airport location and design and can shape thinking on the new reality of multi-airport systems (MAS) and low-cost-carrier (LCC) growth. The following sections provide information on three major international actors selected to represent common, international-level strengths and weaknesses from the perspective of flexible planning.

<u>The International Civil Aviation Organization (ICAO)</u>

Established in 1944 under the Chicago Convention, the ICAO is tasked with promoting the "safe and orderly growth of civil aviation throughout the world" (ICAO, 1997). As such, the organization seeks to promote safety, efficiency, and the rule of law by providing guidance to States regarding the sustainable development of the air transport industry. Among its many initiatives, the ICAO is currently working to tackle the rise of globalization and trans-nationalization, which – according to its documents – have challenged the regulatory regimes established in 1944. In so doing, the International Civil Aviation Organization affects airport design through its *Airport Economics Manual* (ICAO, 2006), a guide to planning and financing airports within uncertain environments, and its *Manual on Air Traffic Forecasting* (ICAO, 1985), which describes various methodologies for predicting future air transport demand.

The International Air Transport Association (IATA)

Established in Havana in 1945 with 57 members from 31 nations mainly in Europe and North America, the IATA now represents over 250 airlines representing 94% of international scheduled traffic (IATA, 2007). Having replaced the International Air Traffic Association which was created at The Hague in 1919, the IATA may be considered the oldest international body with authority over air transport. In modern times, it seeks to represent the needs of the airlines by ensuring the coordinated development of a safe, efficient, and capacity balanced air transport system. Further, the IATA is currently involved in an initiative, "Simplifying the Business," meant to reduce stresses felt by airport passengers during travel. In these efforts, the IATA cooperates with various industry working groups to affect the development of airports and, in fact, coordinates the steering group on European airports (EASG). The representative document of the International Air Transport Association, the *Airport Reference Development Manual* (IATA, 2004) influences the design of airports by promoting ticketless travel and the creation of modular, expandable facilities.

The Airports Council International (ACI)

The ACI, which represents itself as "the voice of the world's airports" (ACI, 2007), was established in 1991 as an integration of the Airport Operators Council International (founded 1948) and the International Civil Airports Association (founded 1962). With over 573 members representing over 1,600 airports and 4.4B passengers served in 2006, the ACI works to support cooperation between various aviation stakeholders and to simplify the passenger experience. Through the *ACI Policy Handbook* (ACI, 2006) the Airports Council International presents recommendation on several issues ranging from the transportation to and from the airport to the location of retail stores to such details as size and type of taxiways, runways, and bridges which ought to be implemented.

Common Strengths of International Organizations

Using the above three groups as exemplars, the various international organizations which affect airport design and operation share several common strengths in terms of promoting real options principles. Foremost, there exists a real recognition of uncertainty and its effects. The ICAO, in its *Airport Economics Manual*, for one, urges due consideration to the "political, legal, economic, social, and technical factors, as well as [to] regional and global developments that may affect the airport" (ICAO, 2006). Similarly, the forecasting manual mentions numerous sources of uncertainty which ought to be identified and accounted for. Further, the documents support the idea of continuous planning, in itself a means of dealing with changing conditions.

Flexibility – said differently, maintaining future alternatives – also provides a common theme. The IATA, for instance, now supports the concept of the modular airport, through which designers may develop "expandable and flexible facilities that can meet airline requirements in a cost-effective manner" (IATA, 2007a). The *Airport Development Reference Manual* furthers the contention, noting that facilities design should incorporate flexibilities which allow for future variations in building usage. As such, the approval of an initial airport design should account not only for current needs but must also allow for the possibility of future expansions and operation changes. Indeed, the IATA suggests that airport operators should seek to expand current facilities (at minimal inconvenience to the customer) in favor of constructing new facilities, whenever possible.

Along different lines, the ACI promotes the development of a common use environment wherein airport infrastructures should provide for multiple uses. The *ACI Policy Handbook* therefore discourages "the use of dedicated systems, wherever clearly defined benefits can be achieved from applying economies of scale … thus avoiding unnecessary and costly capital investments" (ACI, 2006). Together, then, the Airports Council International, International Civil Aviation Organization, and International Air Transport Association currently press – on a base level – many of the principles of real options / flexible design.

Common Pitfalls of International Organizations

Despite the common threads shared by the international groups overseeing air transport, it is clear that many of the world's airports were not – and still are not – constructed for flexibility. Certainly, some of these difficulties stem from the international arena. While attempting to promote the safe and efficient development of air transport, groups like the ICAO, IATA, and ACI nonetheless share pitfalls which prove contrary to the creation of flexible, adaptable airports.

Focus on Forecasting

Despite recognizing the importance of uncertainty, for instance, the documentation printed by international air transport bodies reveals a high dependence on forecasts and master planning. The ICAO forecasting manual, for one, clearly notes the necessity that the Council "foresee future developments likely to require action" (ICAO, 1985), a task which must prove largely impossible given the complexity of air transport.

At the same time, the manuals offer little advice for anticipating and solving the problems of uncertainty. Whereas real options thinking would suggest downplaying the influence of forecasts and focusing on the development an adaptable infrastructure in the first phases of planning, this principle does not appear strongly in the international literature. To the contrary, the ICAO forecasting manual suggests a rigorous process of analyzing the effect of each important, unknowable variable econometrically. Considering the number of variables (Table 4.1) provided by the ICAO, however, this task can prove quite daunting. In fact, the literature itself admits that the data required to accurately plan for each type of traffic at an airport is often unavailable.

Table 4-1: Causal variables typically used in econometric forecasts (adapted from ICAO, 1985)

Type of influence	Variable	Forecast application
Size and spending ability of market	Population/ Number of Households	Passenger Forecasts
	GNP of country or region	All types of forecasts
	Personal disposable income	Non-business passengers
	Exports & imports	Outbound/Inbound international flights
Ethnic or linguistic ties	Proportion of population born in other regions	Passenger forecasts for a route or group of routes
Quality and Price of air service	Published tariffs	Route forecasts
	Revenue yield	All forecast types
	Departure frequency	Scheduled forecasts
	Number of connections on a route	Scheduled route forecasts
	Travel time	Route forecasts
Access to air transport services	Number of destinations served	Regional forecasts
	Proportion of market within a certain distance or travel time from airport	Airport or route forecasts
Price and quality of competing service	Applicable tariffs	Route forecasts
	Departure frequency on competing air service	Route forecasts
	Fare on a competing surface transport service	Route forecasts
	Travel time on competing surface transport service	Route forecasts

Indeed, it should be noted that, even in cases where some of the required variables prove fully predictable, the benefit of the research required would be greatly diluted by the influence of other, unknowable factors. To this end, Caves and Gosling, in their *Strategic Airport Planning*, note the destructive effects of a forecaster's belief in the "myth of predictability": presuming the future will be similar to the past on the basis of trend projections, surveys, and so forth often leads to technological obsolescence and ill-designed infrastructures (Caves & Gosling, 1999). Unfortunately, the suggestions of the international community do little to head off this threat. To the contrary, the focus on master planning may yield the opposite effect by "locking-in" inefficient designs early in the planning process, well before important factors affecting airport traffic and revenue can be determined.

Overlooking the Low Cost Carrier

Other pitfalls include an emphasis on airport concessions and a lack of recognition given to changing conditions in the aircraft industry. The two ideas are directly related. Whereas the ICAO supports fully exploiting the benefits of airport concessions – especially in light of the non-aeronautical revenues brought in by airports like Singapore/Changi (SIN) and London/Heathrow (LHR) – it neither accounts for changes brought on by the growth of the low-cost carriers which typically prefer simpler facilities nor for the development of multi-airport systems which are working to reduce the economic power of single airports. Certainly, truly effective flexible planning must account for these changes by trading off the benefits of building large, expensive airport cities with the gains to be had from attracting low-cost carriers and developing competitive airports within an airport system.

Real Options Solutions and International Organizations

Primarily, it would appear that international air transport literature could further the shared goal of creating efficient, cost-effective airports through changed language. By reducing the emphasis on forecasting and highlighting actual means of implementing flexibility, pitfalls can be better avoided. The following examples illustrate.

Fending off Forecasts: Sydney/Kingsford Smith Airport

One clear step in avoiding disaster lies in eschewing single, deterministic forecasts as the basis for infrastructural planning. Instead, planners may consider joining the ongoing movement to estimate long term (10 – 20 year) forecasts with wide ranges that recognize a spread of possible traffic levels (+/- 30% from the median), depending on experience. Alternatively, planners may choose to develop different regionally-suited scenarios – which themselves can be used to alter the results of independent forecasts – meant to represent different possibilities for airport traffic.

While deciding whether to construct a new runway at Sydney's central Kingsford Smith Airport (SYD), for example, the Australian government found it necessary to consider multiple possible scenarios. Whereas other experts had relied on their own, unique and conflicting forecasts, corporate planner Kinhill Engineers chose to envision three possibilities: low, medium, and high traffic growth (de Neufville, 1991).

Table 4-2: SYD Third Runway - Three Forecasts

Forecast	New Runway Required?
High Growth	Yes
Medium Growth	Yes
Low Growth	No

Table 4-2 illustrates the risk associated with multiple forecasts, as presented to the planners of SYD's third runway. Different forecasts, neither one more plausible than the other, can suggest wholly different strategies for action. Herein lies a principal weakness of master planning literature; the selection of tentative forecasts within the early planning stages color all future decisions.

Kinhill Engineers, however, avoided the risks involved in choosing to support a single forecast. Rather, they eschewed specific numbers and considered the decision to build as a selection between risk profiles. Though a not constructing a third decision could prove workable, they concluded, it involved high risks to the fluidity of Australia's aviation transport system. Building a runway, of course, also carried its own risks and benefits, as presented in Table 4-3. In the end, a comparison of risks and benefits – not a uncertain prediction of traffic – led to the decision to build a third runway at Kingsford-Smith. The Sydney example therefore displays the benefits of avoiding forecasts; applying this real options principle is clearly consistent with creating capacity-balanced air transport systems, a primary goal for international organizations.

Table 4-3: SYD Third Runway - Comparing Strategies

	High Growth	Medium Growth	Low Growth
Build Runway	Good Decision: No Capacity Gap	Good Decision: No Capacity Gap	Neutral Decision: Safer, more efficient runway configuration
No Build	Poor Decision: SYD Congested	Poor Decision: SYD Congested	Neutral Decision: No additional capital costs; higher operating costs due to runway configuration

The Move from Master Planning: Austin-Bergstrom International Airport

In 1991, MIT Professor R. de Neufville, a supporter of real options thinking, commented, "since master planning for airports is flawed at the core, is logically indefensible, and produces unsatisfactory results, it must be replaced" (as cited in Dempsey, Goetz, & Szyliowicz, 1997, p. 471). However, the common literature on airport planning has certainly not abandoned master planning. Even so, changes are underway. While new texts on airport planning emphasize flexibility in planning and an increased recognition of uncertainty (Caves & Gosling, 1999; Kazda & Caves, 2000), successful airports planners have begun modifying their methods. The recommendations of international air transport organizations – and certainly the airports which follow them – could greatly benefit from noting these trends.

At Austin-Bergstrom International Airport (AUS) in Texas, for instance, planners noted an important flaw in traditional master planning: the practice of "freezing" the design concept before detailed planning begun – and well before the construction of the airport started – created a failure risk due to the possibility of unexpected requirements changes. AUS chose to practice a different planning method. By deferring significant design decisions until they were absolutely necessary, planners maintained the airport's operational flexibility as "an effective way to minimize the impacts of potential changes (Ragland, 1998)." This required identifying which airport elements could be decided later, and – once a decision had to be made – designing in flexibility whenever possible while still respecting previous environmental documentation, regional/local rules, etc. In the parking facility, for example, the number of toll plazas can be changed to better accommodate different levels of traffic. There and elsewhere, airport managers also ensured that changes would be possible by crafting professional service agreements (with contractors and other stakeholders) which could be reviewed and modified on a regular basis.

In effect, AUS moved away from master planning's mantra of permanency in order to allow for a phased and continuous planning process. The strategy has paid off. In 2006, the airport – which serves both general and commercial aviation and provides a base for the Texas Army National Guard – successfully catered to over 8.2 million passengers and was awarded recognition by ACI-North America as the United States' best airport in terms of passenger service and satisfaction (Austin-Bergstrom International Airport, 2007). Austin-Bergstrom was completed within a budget of US $800 million and is the property of the City of Austin.

Luring Low Cost Carriers: Frankfurt/Hahn Airport

Whereas much of the formal literature on airport planning from the ICAO, IATA, and ACI do little to mention the emergence of low-cost carriers and multiple airport systems – in fairness, newer documents discuss each in detail, but largely outside of the context of design – Germany's Frankfurt/Hahn (HHN) airport provides an example of success garnered by catering to these changes. In a climate of change that requires the flexibility to adapt, such an oversight clearly jars with the basic tenets of real options.

Despite being located near major airports at Cologne, Frankfurt, and Luxembourg, HHN has proven quite successful at attracting airlines, freight forwarders, and so forth. By actively encouraging the entrance of low-cost traffic, Hahn secured the arrival of Europe's largest low-cost carrier, Ryanair, in April 1999. Specific steps included abolishing landing fees for Boeing 737 weight aircraft (Francis, Fidato, & Humphreys, 2003) and investing in the expansion required to provide sufficient capacity for its rapid growth. In this effort, Hahn spent some € 27 million on renovations before Ryanair arrived (Gillen & Lall, 2004) in order to modify the airport to LCC specifications; the renovations are ongoing.

Fortunately for its investors, HHN has become one of Germany's fastest growing airports. In the fourteen years since its inception as a civil airport in 1993, Hahn has managed to become the nation's eleventh airport in terms of international traffic and its fourth largest cargo airport. The managers currently aim for Frankfurt/Hahn to become Germany's leading low-cost airport.

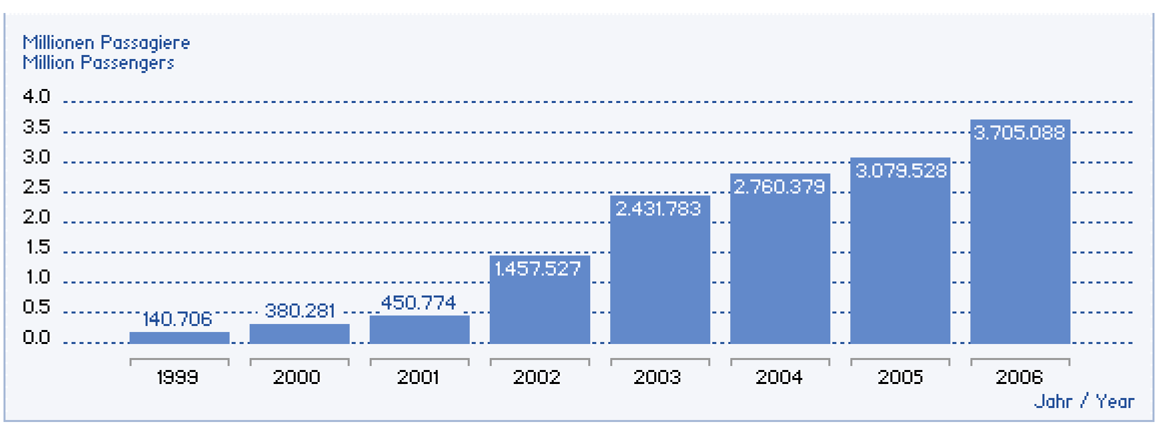


Figure 4-1: HHN passed the 1M, 2M, and 3M passenger mark in 2002, 2004, and 2005 respectively (Frankfurt/Hahn Airport, 2007)

3. The Regional & National Communities

At the national level, governments often seek to improve a national transport system by choosing between road, rail, and air traffic while aiming to create successful monuments to national success. Regional authorities, similarly, select from different plans to compete for global traffic and to benefit the overall economy and environment, betting that the resulting financial growth will exceed the substantial investment required. Residing at this level, national and regional authorities therefore have greater control over airport location and design specifics than their international counterparts. The State of Minnesota, for instance, mandates that 90% of its population should be within 30 miles of a paved and lighted airport and within 60 minutes driving time of an airport with scheduled service (Howard & Keller, undated).

This section analyzes the goals and powers of national and regional air transport groups, noting strengths and challenges with regards to real options planning. The United States Federal Aviation Administration and the United Kingdom Civil Aviation Authority are used as examples of typical national overseers. The represented regional powers are the European Union, which oversees a supra-national region, and the Southern California Association of Governments, which oversees a sub-national region. The section concludes with real options proposals specifically tailored to avoid pitfalls generally associated with groups at this level of airport planning.

The European Union (EU)

Founded in 1993 under the Maastricht Treaty, the European Union is the successor to 1957's European Economic Community. Through its agencies, departments, and forums (European Aviation Safety Agency, European Energy and Transport Forum, Committee on Transport and Tourism, etc.) the Union sets policies for transportation – and therefore for airports – which apply to its 27 member states[7].

Major aviation initiatives include the third package, which is meant to liberalize air travel, create an integrated transport system with common rules and procedures, and to deal with an impending capacity problem. As with many other national and regional bodies, the European Union's transportation program also includes several social goals: economic competitiveness, social cohesion, and cultural development. It is therefore clear that, at this level of decision-making, those who influence airport construction must consider several factors that cannot be "ordinarily" accounted for in airport planning and financial analysis at all. Rather, airport location and design must be balanced against environmental and social effects, the availability of other options (rail, for example), and the promotion of fair competitive practices. The European Union is a case in point. In its control of transportation, the EU affects airports through promoting co-modality, limiting the ability of Member States to direct traffic, setting rules on air carriers, and even by

---

[7] As of July 2007: Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom.

defining airport categories. Further, the Union makes recommendations on airport best practices and has discretionary funds to support airport development.

The US Federal Aviation Administration (FAA)

The United States FAA (as the Federal Aviation Agency) succeeded the United States Civil Aeronautics Administration in 1956. Its goals include increasing safety, providing for greater capacity, and ensuring that the United States shows international leadership in air transport.

The Federal Aviation Administration exerts a great deal of control over airport design. First, it defines the responsibilities of the airport. Again, there is a noticeable focus on issues not directly connected with commercial air transport, reflecting the complex needs of national governments. As such, the FAA requires that airports support national objectives in defense, emergency readiness, and postal services while simultaneously seeking to ensure that consumers are within 20 miles of a set level of air service. Printed documents provide further goals, regulations, and recommendations. These documents include the *National Plan of Integrated Airport Systems* (FAA, 2006), the *Advisory Circular on Airport Design* (FAA, 1989), the *Advisory Circular on Master Plans* (FAA, 2005), and the *2008-2012 Flight Plan* (FAA, 2007).

The UK Civil Aviation Authority (CAA)

The UK counterpart of the Federal Aviation Administration, the CAA, was established in 1972. Unlike the FAA, it operates as an independent aviation regulator without the benefit of government funding. Under this system, it has responsibility over airport economic regulation, airspace policy, safety procedures, and consumer protection. Larger goals include environmental sustainability and the promotion of a diverse and competitive aviation industry. Within the context of this work, it provides an interesting contrast to the Federal Aviation Administration.

The Southern California Association of Governments (SCAG)

Like the European Union, SCAG is a regional body representing a consortium of independent governments. However, though SCAG sets standards for airport development as in the EU, SCAG members are sub-national. Regardless, the goals are largely similar: SCAG promotes economic growth and international trade and supports a functional regional transport system. In addition, the Southern California Association of Governments is obligated to account for local concerns such as maintaining the personal well-being and life quality of its population, supporting community development, and developing a trust between government and citizens. Each of these initiatives affects its airport policies.

Common Strengths of Regional and National Organizations

As with their international counterparts, the archetypal organizations represented here (the EU, SCAG, FAA, and CAA) each demonstrate assets in terms of supporting real options concepts. A focus on continuous planning and maintaining flexibility is particularly apparent. Within the European Union, for instance, there exists a strong emphasis on developing co-modality rather than on "placing all bets" on air transport alone. As a result, great efforts are underway to link airports into a comprehensive transport system. Stockholm/Arlanda Airport (ARN), for example, has three underground rail stations with which it serves its 17M annual passengers. While one station benefits long haul travel, the other two provide a consistent connection between the airport and the city. At the same time – though in a different vein – the Federal Aviation Administration supports initiatives to ensure that small airports maintain room to expand and encourages airport operators not only to design master plans to each particular airport but also to update their airport layout plans regularly.

Other interesting policies include concentrating on integrated transportation networks like at Arlanda (EU, SCAG), unlocking existing capacity at regional airports rather than building new, expensive facilities (EU, SCAG), and requiring that airport planners survey the land *around* a planned airport facility in order to minimize the possibility that the airport may eventually be locked in by urban development.

At the same time, the latest FAA advisory circular on master planning warns that public involvement in the airport planning process should be implemented as early as possible, "before irreversible decisions have been made" (FAA, 2005) in order to avoid future difficulties as have been observed at several facilities worldwide.

The advice of the CAA is also particularly potent, as the Authority supports efforts to ensure that all decision-making occurs in conference with airport customers: airlines and air passengers. Further, it praises the option to defer important decisions until necessary and makes informed references to forecasting, as follows:

> …it is clear that forecasts have to be made because of the long lead-time associated with infrastructure developments. The inevitable uncertainty surrounding forecasts does not imply that such forecasts should be rejected but rather that the conclusions drawn from them should reflect the necessarily simplified nature of forecasting models. In particular, the more detailed the conclusions drawn, the more risk that is likely to overlay them (CAA, 2003).

Common Challenges of Regional and National Organizations

As evidenced both through a light analysis of regional/national documents and through a survey of airport experiences worldwide, national and regional organizations unfortunately suffer from several pitfalls despite the positive points highlighted above. These pitfalls are numerous but solvable, given real options solutions.

Focus on Forecasting: Part 2

Again, it is worth noting that an over-dependence on master-planning and forecasting can prove quite troublesome; the problem seems at least as pervasive on the national/regional level as on the international level. The FAA documents on master planning and forecasting, for instance, provide great detail on the various factors required to create accurate demand forecasts but give little advice on handling inherent uncertainties.

Table 4-4: FAA Chart on Aviation Demand Elements (FAA, 2005)

Required	Included Where Appropriate
Operations (annual)	
Itinerant	Domestic vs. International
Air Carrier	Annual Instrument Approaches
Air Taxi and Commuter	IFR vs. VFR Operations
(Regional)	Air Cargo Aircraft Operations
General Aviation	Touch and Go Operations (Training)
Military	Helicopter Operations
Local	Average Load Factor
General Aviation	Fuel Use
Military	
Passengers (annual)	
Enplanements	Passenger and Cargo Data
Air Carrier	Domestic vs. International
Commuter	General Aviation Passengers
Enplanements	Helicopter
Originating	Air Taxi
Connecting	Other
	Number of Student Pilots
	Number of Hours Flown
Aircraft	
Based Aircraft	Average Seats/Aircraft
Aircraft Mix	
Critical Aircraft	

Equally disconcerting, the same document, though supporting the development of a range of forecasts including high and low passenger traffic, nonetheless advises that airport planners seek to settle on the most likely scenario within this range. Although the literature later asserts correctly that "having a range of forecast activity allows airport planners to develop flexibility in facilities" (FAA, 2005), the contention that planners ought to eventually settle on a "middle-path forecast" carries significant risk as demonstrated by the flaw of averages (Chapter 3). Simply recounted, building an airport for 10 million passengers is a poor solution when given a high forecast of 20 million and a low forecast of no passengers at all.

Speculating on Traffic: Montréal/Mirabel and Washington/Dulles

Another common danger, made obvious by airports such as Canada's Montréal/Mirabel (YMX), lies in guessing where air traffic will develop or in making assumptions as to airline or passenger traffic patterns. In general, the government record for siting major facilities based on these assumptions is rather poor. Mirabel, for instance, was opened in 1975 under the assumption that Montréal would develop into Canada's economic center. Constructed to accommodate 4 million passengers in its first year and over 40 million by 2025, Montréal/Mirabel – then the world's largest airport by size – never served more than 3 million people per year and is currently destined to be sold at great loss as an amusement park (Canadian Press, 2006). Simply stated, the airport never experienced the rapid customer support expected by the government which supported its creation.

Washington/Dulles Airport (DIA) provides a similarly interesting case. Here, the United States government tried – and failed – to forcibly direct traffic to its new airport by passing a series of prescriptive regulations meant to make DIA the region's international airport. However, airlines circumvented the regulations in favor of Washington/National (now Reagan) and Dulles remained underused for nearly two decades (de Neufville, 2000). In Europe, the French government would later experience similar difficulties in developing Paris/de Gaulle as an alternative to Paris/Orly. Though both Dulles and Orly have surpassed these issues – Dulles became a United Airlines hub and de Gaulle surpassed Orly in 1991, 25 years after its opening – the examples remain informative. Even powerful governments can experience great difficulties in forecasting or directing specific traffic types at a specific airport, especially in multi-airport regions. Unfortunately, the documents provided by several national and regional bodies do little to give information on and to avert these problems.

Presumptions about People: Osaka/Kansai International Airport

Another pitfall lies in the inability of governments to accurately predict public support for an airport. Though the FAA planning circular does emphasize the necessity of generating public support, a few examples of past problems may prove useful. At Osaka/Kansai (KIX), for one, the Japanese government proved unable to predict public reaction to the new airport. Hoping to relieve complaints regarding noise at Osaka/Itami International Airport (ITM), the government opened Osaka/Kansai in 1994 on an expensive man-made island. However, the airport met significant difficulties when the people who initially seemed to support the airport shied away from it in favor of the more conveniently located ITM. Despite rapid passenger growth and some of the world's highest airport fees, Osaka/Kansai consistently posts financial losses; its US $15 billion dollar debt is expected to take over 30 years to liquidate (Dempsey, 2000). Certainly, few airport investors could withstand such a dilemma.

Making Monuments: Mirabel and Kansai revisited

Yet another potential difficulty in the planning of airport capacity on the national and regional levels lies in the desire to create monuments to local prosperity or as engineering marvels. The reasons for doing so are obvious: being important points of entry, airports often provide visitors with their first introduction to a city, nation, or region. However, it ought to be noted that monuments are often large and quite expensive. Moreover, given their size and importance, monuments may rely on overly favorable forecasts and are difficult to plan incrementally. As examples, one may again note Montréal/Mirabel and Osaka/Kansai. Mirabel was constructed to serve as Canada's premier gateway and today serves no passengers. Kansai's recognition as a Civil Engineering Monument of the Millennium (ASCE, 2001) likely does very little to offset its massive debt. Even in cases where an airport finally reaches capacity – as Washington/Dulles did two decades after it was constructed – significant money is wasted in the intervening period of under-use.

Prescription Airports and other Difficulties

In its policy paper, *The Future Development of Air Transport in the United Kingdom* (CAA, 2003), the UK Civil Aviation Authority details its own list of "potential pitfalls" for governments involved in the development of airports. Aside from those already listed above, other pitfalls noted by the CAA include the risk of creating airports according to inadaptable blueprints and investing in airports of poor commercial potential.

Other difficulties include a lack of recognition for the influence of low-cost carriers and multiple airport systems and failing to provide methods for integrating flexibility into infrastructure, both of which will be addressed further on in the chapter.

Real Options Solutions and Regional/National Organizations

Certainly, national and regional organizations must accommodate and balance several desires: regional development, constructing monuments to success, environmental/social responsibility, and – of course – ensuring the financial viability of their investments. The following examples provide some real options solutions for balancing those priorities.

Landbanking: Sydney's 2nd Airport

For over twenty years, the government of Australia has sought to develop a second airport for passengers flying into the nation's largest city, Sydney. Given that Australia depends on air transport in order to manage the distances between its major cities, siting a new airport is particularly important; the current airport, Kingsford-Smith (SYD), is difficult to expand due to its closeness to the city center. One solution, certainly, would have been to build a second airport at a site chosen based on the forecast air traffic growth. However, this would have exposed Australia to the difficulties experienced at Mirabel and Dulles. Alternatively, the government could have chosen to defer action on a new airport entirely, thereby risking the possibility that no site would be available once it became needed. Rather, the government protected itself by purchasing the land required to build an airport *in case* it became necessary and deferred the decision on actually building a new airport. This practice, known as landbanking, ensures that national and regional governments can control zoning and development in areas of concern. As such, landbanking, which can be financially provided for by national organizations such as the FAA (FAA, 1997), can offer solutions to several difficulties. In the case of Australia, the purchase of land at Badgery Creek provided a contingency which satisfied different parties without requiring a commitment to build a new airport; a potential capacity constraint was avoided at relatively low cost[8].

At the regional and national levels, the practice of landbanking can be applied more widely and can help avoid the pitfalls of speculating on where traffic will develop or

[8] Indeed, it should be noted that the government applied several real options principles. Aside from landbanking, Australia chose to build an additional runway at Kingsford-Smith, thereby allowing it to delay an expensive, and (at that time) unnecessary decision the new airport (de Neufville, 1991).

presuming that the local population will choose to support a particular airport project. By purchasing multiple sites, regional and national authorities can, in effect, "hedge" against uncertainty.

A hypothetical example provides some insight. One may consider a case in which a national or regional government intends to construct a new international airport gateway. Given correct information regarding how various regions or cities will develop economically and which would attract the greatest amount of traffic over time, selecting an airport site would be simple. However, without such data, the risk of repeating Mirabel would prove quite daunting. A 2003 report prepared for the United States Assistant Secretary for Aviation and International Affairs hints at a possible solution: by maintaining the right to construct that airport at multiple sites, the government can defer decisions on where to build until more information becomes available (GRA Incorporated, 2003). Given that the cost of purchasing land constitutes only a small fraction of total airport costs, this course of action appears quite feasible. Table 4-5 uses data from Denver International Airport, the world's largest airport by size, to support this point.

Table 4-5: Airport Development Costs at DIA (Dempsey, 1997)

Airport Action	Cost to Region *(undiscounted US dollars, millions)*
Land Acquisition (1 Purchase)	$241.6
Land Acquisition (2 Purchases)	$483.2
Airport Construction Costs	$3,003.9
Miscellaneous Planning Costs	$986.3
Actual DIA Total Cost[9] (1 Purchase)	$4,231.8

Assuming that the hypothetical lawmakers above decided to construct a new airport some ten years before the airport's completion (as at Denver) and that airport costs paralleled those at DIA, the cost of the land acquisition would be $241.6 million, or 5.7% of total airport costs. Securing a second plot would increase that figure by the same amount; assuming that the government decides to keep both purchases, some $241 million would be lost. However, if the lawmakers selected a single site and prematurely built an airport at the incorrect location, total losses would potentially rise to over $4 billion. Conversely, deciding not to purchase any land at all would risk forfeiting the ability to build an airport anywhere due to urban encroachment. In the case of Denver International, the Rocky Mountain region would have forfeited its primary commercial airport along with the economic benefits of 21.7 million passengers emplaned in 2005 alone (FitchRatings, 2006). Thus stated, the immense benefit of landbanking in order to preserve airport alternatives – relative to the small costs – appear quite clear. The practice can simultaneously serve national goals of capacity management, economic development, and cost-efficiency at relatively low risk.

[9] This figure does not include cost overruns at DIA. With overruns included, DIA cost US $5.3B (Dempsey, 1997).

Remodeling Military Airfields: Frankfurt/Hahn and Austin-Bergstrom

Another twist on the practice of landbanking involves transitioning former military airfields into commercial airports. This process has several benefits. Maintaining operations at a military airfield not only ensures that the land is available for future use but also helps to ensure that the area will be established and publicly accepted as an airport. Further, reusing military aviation facilities can help reduce the total costs of constructing a civil airport. In 2003, one transportation consulting firm even went so far as to suggest a policy of mandatory landbanking of all military airports with no current aviation use, except in regions where the need for increased aviation capacity seemed extremely unlikely (GRA Incorporated, 2003).

So far, the model has shown some success. Frankfurt's successful Hahn airport (HHN), for instance, sprung from Hahn Airbase, one of the largest Cold War air force bases in Europe. Investments into expanding Hahn, which showed an operating profit for the first time in 2006, totaled €135 million between 1998 and 2005; by comparison, Cologne/Bonn Airport (CGN) spent €325 million on its Terminal 2 alone (Airport-Technology.com, 2005)[10]. Across the Atlantic, Austin-Bergstrom International Airport (AUS) grew from the foundations of Bergstrom Air Force Base, which the military commissioned during World War II. The airport, which ranked number 50 in US enplanements in 2003, cost less than US $800 million. By comparison, the new runways alone at Baltimore Washington International Airport (BWI; number 24 in enplanements) and at Louis Armstrong New Orleans International Airport (MSY; number 50 in enplanements) will cost US $600 million and US $452 million, respectively (FAA, 2003).

Incremental Development: Dallas Fort Worth International Airport

Though landbanking may provide a remedy for governments looking to avoid incorrectly speculating on when, where, and how air traffic will develop, it does little to counter tendencies to build colossal airport monuments well before they needed. In 2004, the IATA, while recognizing the responsibility of national and regional governments to provide for growth, suggested the use of incremental development (or phased expansion) as a suitable alternative to building superstructures right away:

> It is advisable for national governments to develop a strategic planning objective for medium and long-term development of airports within their national jurisdiction. This strategic proposal should look at existing air traffic control as well as runway and terminal capacities and then should define strategic objectives for the phased expansion or development of new or existing airports. (IATA, 2004, p. 37)

---

[10] It is interesting to note that, in a feat of incremental development and civil-military conversion, Hahn's first terminal had been the Officer's Mess of Hahn Air Force Base; the terminal served Hahn for seven years.

A review of Dallas/Fort Worth International Airport's (DFW) master plan reveals the success of this thinking. Established in 1974, DFW – the central airport of the Dallas/Fort Worth Metroplex – has emphasized the use of a phased capital improvement plan meant to ensure the "goal of incremental or phased development that is timely and logical" (Dallas/Fort Worth International Airport, 1997). As such, its 20 year, US $5.5 billion dollar capital improvement plan has been broken down into three phases; continuous planning and proactive management techniques, meanwhile, have been designed to focus on market-based action. In other words, DFW's strategy is to operate like a business: all investments require input from the airport stakeholders and must directly correlate with providing soon to be needed capacity.

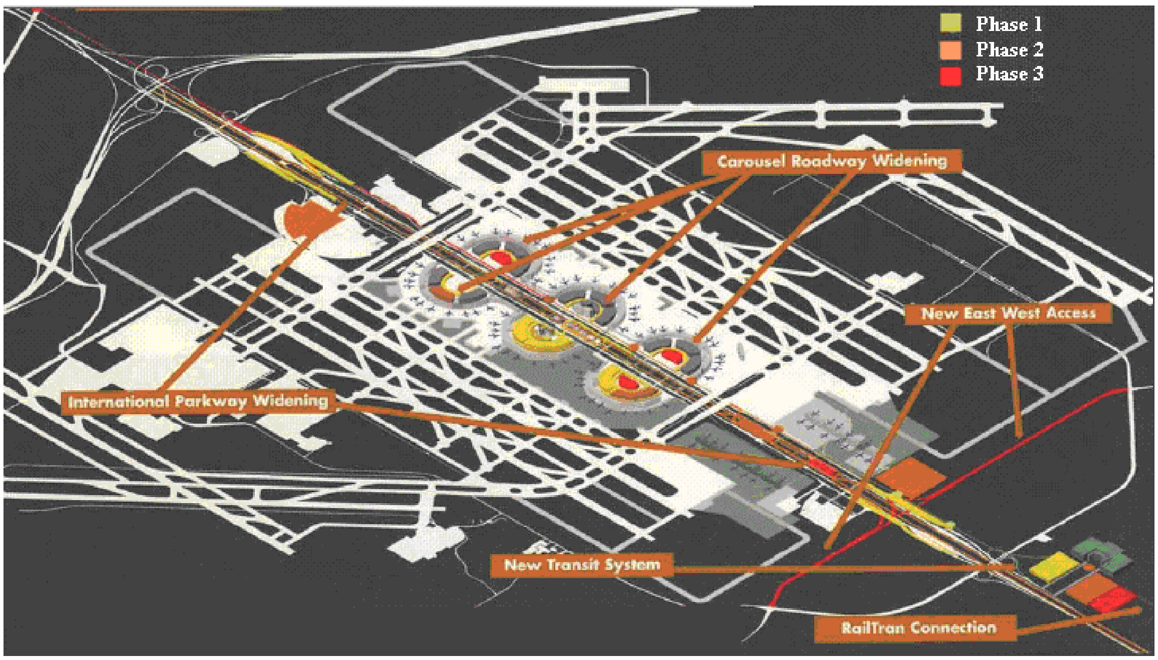


Figure 4-2: DFW 1997 Capital Improvement Plan (Dallas/Fort Worth International Airport, 1997)

Dallas/Fort Worth's terminal area development program seems particularly telling. James Crites and Larry Bauman, while commenting on the Airport Development Plan, noted that the program differs from those supported by traditional master planning; rather than evaluating the airport's ability to fund new infrastructure only after the capital improvement plan is complete, DFW planners sought a continuous planning approach which integrated financial planning during each stage (Crites & Bauman, 1998). Further, the DFW approach avoids building or demolishing infrastructure until absolutely necessary. Rather, the plan maintains the flexibility to choose between different growth concepts for as long as possible. Though safeguarding the possibility of major additions, DFW need not commit to any expenditure until demonstrated traffic patterns demand it.

GATE PHASING

Existing	Phase 1 (1999-2004)	Phase 2 (2005-2009)	Phase 3 (2010-1019)
122	171	204	250

TERMINAL CAPITAL INVESTMENTS

Phase 1	Construction of Terminal 3W (27 gates) and 4W (14 gates)	$832 million
	Improvements to existing terminals	$147 million
	Automated people mover system	$668 million
Phase 2	Expansion of Terminal 4W (13 gates) and construction of Terminal 5W (20 gates)	$626 million
Phase 3	Expansion of Terminal 5W (15 gates) and construction of Terminal 5E (31 gates)	$741 million

Figure 4-3: DFW Terminal Phasing (Dallas/Fort Worth International Airport, 1997)

Certainly, DFW's efforts have bore fruit. In 1997, the airport recorded its community impact at US $11 billion including US $6 billion in wages and salaries for its 200,000 employees. In 2006, its 7 runways, 5 terminals, and 152 active gates gained substantial praise. The sixth largest airport in the world in terms of passengers served with 60.4 million people passing through in 2006, CNN recognized the airport's incredible transformation due to the addition of a new terminal and effective internal train system; better yet, the Airports Council International named Dallas Forth Worth International 2006's number one airport in the Americas in terms of customer service and the fifth best airport in the world (Dallas Forth Worth International Airport, 2006).

Looking (again) to LCC's: Liverpool John Lennon Airport

Although constructing airports so as to cater to low-cost carriers is not in itself a real options principle, maintaining the ability to serve different customer segments is. There are therefore several reasons for revisiting low-cost carriers within the context of flexible planning. First, numerous national civil aviation authorities operate with the intention of developing air traffic in underserved regions, a particular strength of the low-cost carrier. Second, government has a poor track record of determining what type of air traffic (domestic, international, network carrier, or LCC) will develop where and when. Finally and most importantly, low-cost and network carriers (NC) often demand different services from the airports they patronize; as a result, the ever-changing landscape of air transport may demand that new and developing airports have the flexibility to serve either customer.

Liverpool John Lennon Airport (LPL) provides an interesting case. In an environment where the Civil Aviation Authority supports a national aviation policy which operates only in broad strokes and otherwise allows local officials to solve problems with a degree of independence, Liverpool has grown largely without government intervention (Civil Aviation Authority, 2003). Partly due to the influence of low-cost carriers, Liverpool has become one of Europe's fastest growing regional airports; scheduled international traffic increased from 189,000 passengers in 1997 to over 1.7 million just five years later (*Ibid.*). Indeed, when Ryanair celebrated carrying its 7 millionth passenger to the airport in 2007 (after having established services there in 1988), the Lord Mayor of Liverpool noted that Ryanair had helped put the city on the map (Liverpool John Lennon Airport, 2007). As a result, LPL is an example of how due attention to changing conditions in air transport – namely the rise of the low-cost carrier – can help national governments attain regional development goals.

Table 4-6: Growth Pattern of Liverpool John Lennon Airport (Civil Aviation Authority, 2003)

Scheduled International Passenger Service from Liverpool John Lennon Airport							
9-Jun-1993		11-Jun-2003		9-Jun-1993		11-Jun-2003	
Time	Destination	Time	Destination	Time	Destination	Time	Destination
		6:00	Palma			13:55	Paris CDG
		6:15	Amsterdam			14:00	Dublin
		6:30	Malaga			14:15	Alcante
		7:00	Nice			15:45	Amsterdam
		7:50	Barcelona			16:00	Charleroi
		7:55	Dublin			16:55	Nice
8:50	Dublin	8:00	Paris CDG			17:55	Barcelona
		9:45	Amsterdam			19:05	Amsterdam
		12:00	Geneva			19:15	Paris CDG
		12:35	Amsterdam			21:05	Malaga
		12:35	Madrid	21:55	Dublin	21:40	Palma
		13:55	Malaga			22:15	Dublin

4. The Airport Level Community

Having investigated the goals and efforts of various international, national, and regional groups, one set of airport stakeholders remains: those on "the airport level." These groups, unlike their counterparts above, interact directly with the airport and its administrators as airport managers, passengers, airlines, and community members. With this level of closeness, stakeholders at the airport level bring new goals and powers. The viability of real options solutions increases. In order to illustrate this point, three groups are examined in detail: airport manager BAA, low-cost carriers Ryanair and easyJet, airline group Star Alliance, and the airline passenger.

BAA

Created in 1965 as the British Airports Authority, BAA became the first major airport authority to go private in 1986. Today, it owns and operates seven airports in the United Kingdom including Heathrow, Stansted, and Glasgow while maintaining management contracts at several major airports including Baltimore Washington International (BWI) and Logan International (BOS). At its UK airports, BAA holds direct responsibility over several functions directly tied to airport design: the management of retail facilities and car parks, provision of airport utilities, operation of flight information systems, and the development of transportation to and from the airport all fall within its purview. Given this list of activities, the influence of BAA and other airport owners and managers on airport design is difficult to underestimate.

Our businesses

UK airports	Rail	Retail	Property	International airports
We own and operate seven UK airports: Heathrow, Gatwick, Stansted, Southampton, Glasgow, Edinburgh, Aberdeen.	We own and operate two public rail services: • Heathrow Express services run to all four terminals at Heathrow Airport • Heathrow Connect services run to Terminals 1, 2 and 3 at Heathrow Airport.	World Duty Free is BAA's wholly owned tax and duty-free business comprising 65 stores. We also lease premises to around 600 retail outlets and 180 restaurants.	BAA Lynton is our commercial property arm that acquires, develops and invests in real estate on and around our airports. It has £910 million of property interests and its main role is managing the Airport Property Partnership, a 50/50 joint venture with Morley Fund Management.	We manage the following airports: Hungary (Budapest Airport*), Italy (Naples), Australia (Melbourne International, Perth International Airport, Launceston Airport Tasmania, Northern Territories Airports), USA (Indianapolis International Airport). We manage retail operations at the following airports: USA (Baltimore Washington International Airport, Boston Logan Airport, Pittsburgh International Airport).

* Sold in June 2007.

Figure 4-4: Functions of BAA (Source: BAA website)

Current BAA initiatives include emphasizing communication with the local communities affected by their operations, increasing surface access to its airports, developing an integrated network strategy, and reducing the negative environmental impact of all elements of air travel while continuing to grow the industry. Of course, maximizing the financial value of its holdings also remains a key goal.

Ryanair and easyJet

As Europe's leading low fare carriers, Ryanair and easyJet have already exerted significant influence on airport design. Together, they make significant demands on airport facilities, capacity availability, and landside accessibility. Ryanair's significant power to draw passengers, for instance, led Frankfurt/Hahn to spend € 27 million on renovations before the airline even arrived; elsewhere, London/Luton Airport (LTN) built better ground access to support easyJet's expansion, though the airline later criticized the resulting increase in fees (Dennis, 2004). Elsewhere, low-cost carriers have made demands for single-storey terminal buildings, lower rates at car parks, and catering facilities tailored to their clientele.

Less directly, easyJet and Ryanair also influence airport design by emphasizing a business strategy quite different from that of traditional network carriers. Ticketless travel, for instance, is reshaping terminal check-in. Further, easyJet is currently pursuing efforts to change EU regulations on emissions and to develop new eco-jets, both of which could have significant effects on airports worldwide.

The Star Alliance

Founded in 1997, the Star Alliance is one of multiple airline consortiums which are shifting the balance of power between airlines and airports while acting to better compete with low-cost carriers. Counting United Airlines, Lufthansa, and Air Canada amongst its members, the Star Alliance serves some 855 airports and generates over US $1.1 trillion in annual revenue.

Several Star Alliance initiatives have significant power over airport design. While pursuing its goal of enhancing the competitive position of individual airlines and increasing customer benefits, the Alliance has pushed for the increased use of shared facilities and pioneered its own alliance-wide self-service kiosks and electronic ticketing system. Further, the alliance has published its own master plan for Los Angeles/International (LAX) and pushed the co-location of its airlines at airports including London/Heathrow, Miami/International, and Tokyo/Narita, where 12 alliance carriers have shared the same space since June 2006.

The Airline Passenger and Airport Locals

Finally, the individuals who patronize and/or reside near airports can have a significant influence over airport location and design. Airport locals, for one, have demonstrated a remarkable ability to stall airport construction projects by citing legitimate concerns about noise, increased traffic, or environmental and social degradation. Passengers, on the other hand, demand efficient operations, short traveling times to and within the airport and terminal facilities that specifically cater to their needs. Certainly, neither group can be set aside in the planning, construction, or management of a successful air transport facility.

Common Strengths of Airport Level Organizations

More so than any other group, airport level organizations may derive their greatest strength from an inherent closeness to the shareholders who demand value and to the customers who use airports themselves. As such, these groups are forced to internalize the true social and environmental costs of air travel – as emphasized in BAA policy documents – and to focus on minimizing costs and maximizing profit over the long term. This combination of traits makes airport level organizations (notably airport operators and the airline users) prime candidates for implementing real-options-inspired, flexible solutions. As such, the Star Alliance has openly sought the benefits of shared spaces capable of serving more than one airline; low-cost airlines, meanwhile, have shied away from monument-building and those in residential areas have supported controlled airport growth.

<u>Common Pitfalls of Airport Level Organizations</u>

Despite the strengths of airport operators, airlines, and passengers, airports worldwide nonetheless suffer from several difficulties which beg real options fixes.

Capacity Constraints

Airport designers and planners widely accept that airports built in or near urban areas can prove rather difficult to expand. Urban encroachment, noise concerns, and issues of safely flying aircraft over population centers can each limit an airport's growth prospects, as has now occurred at heavily congested London/Heathrow (LHR) and Los Angeles/International (LAX) Airports.

Urban areas are not the only source of capacity constraints, however. Rather, Stockholm/Arlanda International Airport, (ARN), which is located approximately 25 miles from Stockholm, faced expansion difficulties due to environmental concerns. Other facilities have suffered due to the failure of initial planners to anticipate the need for future growth. de Neufville and Odoni noted of Heathrow, for instance, that the location of its landside facilities along the airport's central axis – a placement which otherwise helps to ensure better airfield traffic circulation – has the side-effect of limiting its expansion (de Neufville & Odoni, 2003).

Uncertain Traffic Levels and Demand Peaking

Capacity constraints need not be constant. Rather, many airports experience difficulties due to fluctuations in traffic. Multiple factors contribute to the dilemma. On one hand, seasonal peaking may occur due to increased tourist traffic during the summer months, as at London Luton. Otherwise, most airports experience daily peaks in traffic due to airline scheduling. Peaking presents an interesting problem. Though airports must provide enough capacity to handle peaks, this can lead to under-use once the peak has passed. The difficulty present here is clear: airports must balance the need for spare capacity and the desire to minimize waste. According to Odoni, may airports planners fail to find this balance; errors in calculating peak-level capacity demands are quite common (Odoni & de Neufville, 1992).

Duplicating Expenditures: Kansas City International Airport

Multiple investigators, including Professors de Neufville of MIT (de Neufville, 1995a) and Trani of Virginia Tech (Trani, 2002), have considered the effects of airport configuration on an airport's ability to provide maximum value. Some conclusions of particular importance to flexible design may be determined. Both observers, for instance, comment on the use of decentralized facilities – wherein passengers enter the airport at separate landside access points – with de Neufville noting that the design is now generally avoided by large airports[11].

Kansas City International Airport (MCI) provides a compelling case for this ethos. Opened in 1972, MCI has been recognized as extremely friendly largely because originating passengers can rapidly move from the entrance of one of its three decentralized terminals and to their airplanes after having traveled only a few hundred feet. There is a serious problem, though: because of its decentralized design, MCI must pay for significantly more security equipment and terminal personnel as it would were it to have a centralized terminal access point. In fact, the airport's aviation director commented in 2007 that MCI would soon have no choice but to replace all three terminals with a single facility as is common at other major airports, thereby cutting costs by creating one security complex while giving passengers a central area in which to purchase food and retail goods (Heyward, 2007). Of course, the price tag of such a major reconstruction – which may require the demolition of some or all of the current terminals – will prove quite expensive, the result of inflexible choices made over thirty years ago.

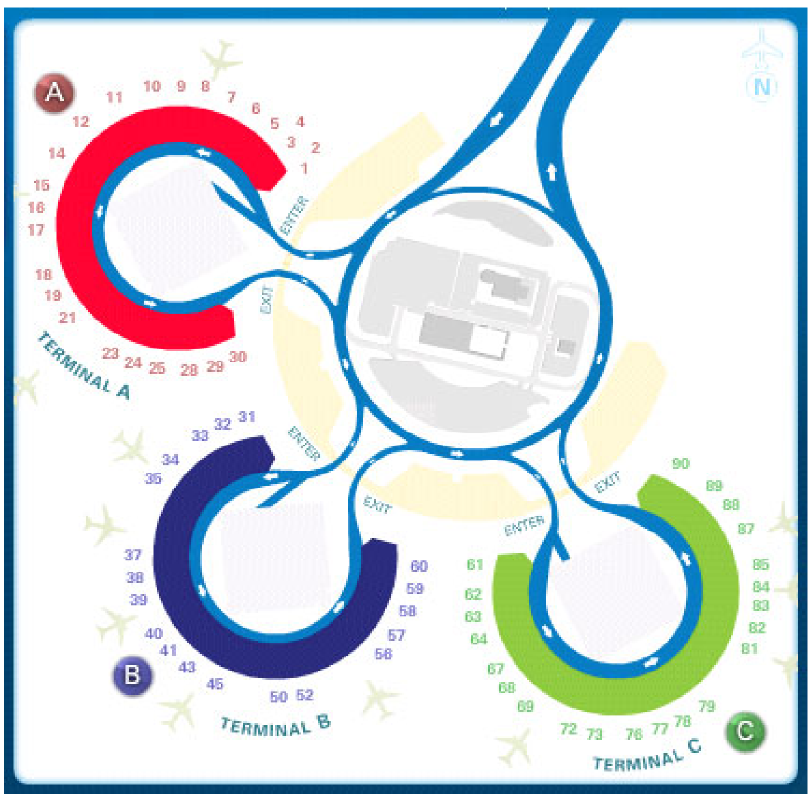


Figure 4-5: Three decentralized terminals at MCI (Kansas City International Airport, 2007)

[11] It should be noted that some airports have been successful with variations of the decentralized model, including Dallas Forth Worth (DFW) and Paris Charles de Gaulle (CDG).

Finalizing functionality: Baltimore/Washington International Airport

Aside from capacity and expansion problems, airport level groups also tend to face difficulties resulting from assumptions about exactly what services an airport or airport terminal will provide. Multiple examples demonstrate the risk of constructing airport facilities to the specifications of a single customer or customer group. At MCI, for instance, designers failed to plan for the possibility of high transfer traffic and created terminal structures wholly unsuitable to the hubbing operations of TWA, which abandoned headquarters there in 1982.

Baltimore/Washington International Airport (BWI) provides another example due to its misfortune in dealing with US Airways during the 1990s (de Neufville & Odoni, 2003). After having constructed an international terminal for the airline, BWI found itself with an underused facility when US Airways relocated its international facilities to Philadelphia. Unfortunately, due to a lack of flexible design principles, the terminal could not be used to supplement the need for new service areas elsewhere. As a result, when it became apparent that Southwest required additional space in order to support its growth, BWI was forced to spend an additional US $100 million in order to create duplicate facilities. The decentralized international terminal was simply too far away from other facilities and not correctly designed to support new customer demands. In finalizing the function of its US Airways terminal, BWI made itself vulnerable to unforeseen fluctuations in customer demand.

<u>Real Options Solutions and Local and Private Investment Organizations</u>

As on the international and national/regional planning levels, several real options planning solutions are available for those groups which actually plan and operate the world's airports. In many cases, the costs and benefits of each alternative have been studied, quantified, and put into practice. Detailed studies have been undertaken by de Neufville, Trani, and Belin (Belin, 2000), among others. A few findings are listed below. However, as the implementation of real options generally requires detailed engineering studies and adaptation to each particular case, the following examples are not meant as suggestions for any particular airport. Rather, they represent successes in flexible planning, many of which are best considered during the early phases of airport development or expansion.

Ensuring Expandability: Landbanking at the UPS WorldPort

Whereas the growth of other airport facilities has been limited by the encroachment of urban developers, stakeholders at the UPS WorldPort sorting hub in Louisville, Kentucky have managed to avoid these difficulties. The WorldPort, which lies at the center of the of the UPS global network, is expected to increase in size from 5.1 million square feet in the coming years by adding 1.1 million square feet in building space and up to 3.6 million square feet in aircraft ramps (Bruns, 2006). After the expansion, the facility will be able to handle as many as 136 aircraft on the ground at the same time while continuing to significantly contribute to the financial stability and job market of the surrounding area. The phenomenal expansion has not been perpetrated by fortune; rather, UPS has commented that its decision to remain in Kentucky and to expand its operations there are the result of aggressive landbanking on the part of the Louisville Regional Airport Authority, which continually purchased land around the site in order to ensure the possibility of later growth. As such, the continued success of the UPS WorldPort provides an important example wherein the purchase of land assets before they became necessary and close cooperation between airport level organizations has produced positive results.

Ensuring Expandability: Take 2

Outside of landbanking, several other measures can assist in helping airports to expand their capacity as demand requires. Among these, appropriate choices of internal transport systems can foster sustainable, low-cost development. Hong Kong International Airport (HKG), for instance, opted to provide intra-airport transportation using a self-propelled – rather than cable driven – system of people movers. As a result, HKG – which was named the 2nd best airport worldwide by Skytrax Research Advisors in 2006 (Skytrax, 2007) – can add cars and routes to support new passengers and facilities at minimum cost (de Neufville & Odoni, 2003). Although the capital costs of self-propelled systems tend to be higher, the additional flexibility provided may well offset any additional costs and be cost-saving in the long term.

Busing has similar benefits. Whereas fixed transportation systems such as rail are difficult to alter in terms of capacity and endpoints, buses can be deployed to different locations only as necessary. At New York/Kennedy International Airport (JFK) for instance, buses are deployed during seasonal peaks to deal with increased traffic levels. As such, the airport operator only incurs additional transportation costs when the capacity is needed; without such flexibility, the airport would be forced to suffer either from overcapacity during low-traffic periods or under-capacity during high-traffic periods. Both instances, of course, lead to losses in profitability.

Self-propelled people movers (including buses) can yield additional benefits to new airports; both provide a relatively inexpensive means of transport without forcing airport operators to commit to more fanciful systems before the success of the airport has been proven. Further, when compared to expensive internal rail systems, self-propelled people movers can help reduce overall airport costs and make the facility more favorable to growth-stimulating low-cost carriers.

Other flexible design approaches can be applied to baggage carriage systems and to terminal design. As studied by de Neufville, basic tug and cart systems seem to provide a good option for unproven airports wishing to practice incremental development. Linear midfield concourses, meanwhile, seem to allow for greater flexibility and expandability. Both alternatives therefore offer the option to avoid monument building and expand only as needed. At Denver International Airport (DIA), for example, tug and cart systems provided sufficient abilities before their advanced baggage systems were functional; their terminal design, in addition, allows for easy extension of linear concourses (de Neufville, 1995a).

Learning to Share: Shared gates and Common User Systems

Airport owners and operators are not alone in their growing avoidance of monuments. In order to better compete with low-cost carriers and with each other, airline consortia have also joined the movement in an effort to reduce operating costs, develop their customer bases, and increase profitability. Whereas the airlines of yesterday may have demanded fantastic terminal facilities with which to demonstrate market superiority, the modern approach is far more timid. A 1995 article in the ASCE Journal *Civil Engineering* explains:

> The days of high-flying airport terminal projects are over. The 1980's philosophy of 'build it, and they will come' has been replaced by a new approach designed for a more conservative era in commercial aviation: Don't overbuild, but be prepared to change. … This new philosophy of terminal design has several impacts: Terminals are being designed for incremental expansion, with the ability to expand quickly and efficiently as traffic growth dictates. Airports are striving to attain maximum efficiency from existing space, undertaking renovation projects and finding interim uses for the conservative amount of spaces built in anticipation of future demand (Reiss, 1995).

The terminal and gate sharing supported by airline groups including the Star Alliance contributes an important element to increasing airport efficiency and to preventing the duplication of expenditures. Shared lounges, for one, have multiple benefits over individual lounges. First, they reduce overall space requirements. Whereas individual lounges must each have the capacity to handle the aircraft assigned to them, lounges which serve multiple gates do not require the capacity to service each gate (and its aircraft) at once. Rather, shared lounges account for the fact that multiple gates are not often used simultaneously. As a result, sharing lounges between four gates can reduce space requirements by 85% over building a separate lounge for each gate (Belin, 2000). This tends to increase the overall occupancy rate of the space, thereby decreasing waste associated with under-use. Second, shared lounges make it easier to relocate passengers from one gate to another, adding an important element of flexibility.

Shared terminals and gates, also instrumental to the Star Alliance “under one roof” initiative, provides similar benefits. Whereas passengers connecting from one Alliance flight to another gain in terms of ease of transfer, the airlines are able to share the costs of maintaining a terminal. In addition, sharing requires fewer retail and service areas, again reducing unnecessary duplications of effort.

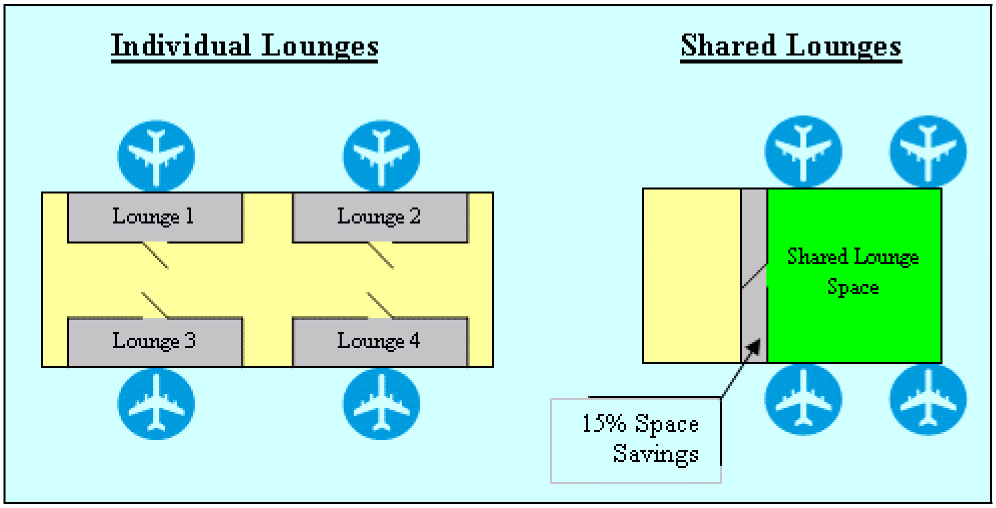


Figure 4-6: Size Benefits of Shared Lounges (Adapted from Belin, 2000)

Common user systems provide another element critical to the sharing concept. By standardizing the systems which each passenger uses to check-in, handle bags, and conduct business, airports can move away from the paradigm of carrier-dedicated spaces. This mitigates the risks associated with finalizing one particular function per area. Therefore, if a carrier decides to relocate, its former space can be quickly and inexpensively converted to serve another airline (network or low-cost) or passenger group (first class or coach, domestic or international). Numerous airports worldwide have found success with these efforts. In 2002, for instance, Geneva/Cointrin International Airport (GVA) signed on to a Common Use Terminal Equipment (CUTE) system for its check-in and departure areas with the expectation of having over 40 airlines operate the same system. After its success with the system – which was designed to increase operational effectiveness by 25%, reduce passenger waiting time, and minimize the amount of space required for dedicated check-in areas – GVA chose to upgrade to the more advanced Common User Self Service (CUSS) kiosks in 2006.

Making Facilities Modular: Munich/Franz Josef Strauss and London/Stansted Airports

Sharing aside, numerous other design decisions can contribute to combating the provision of dedicated terminals and the risks associated with dependence on a particular airline or type of passenger. Together, modularity and multi-functionality can provide real options methods for minimizing difficulties such as those experienced at Baltimore/Washington International (BWI) and Kansas City International (MCI) airports.

Munich/Franz Josef Strauss (MUC) and London/Stansted (STN) have both established a track record for employing modular designs to this effect. Munich's Terminal 1, car park guidance system, and Terminal 2 baggage service all include elements of modularity. The 25 mile baggage transport system, for one, consists of redundant structures and standardized components which allow it to change its capacity through the addition or removal of specific modules. Terminal 1 also provides for adaptability. With the completion of Munich's Terminal 2, airport managers knew that the central carrier, Lufthansa, would decide to leave Terminal 1 in favor of newer facilities. As a result of

Terminal 1's modular design, though, the risk of having an underused facility had been mitigated. Indeed, MUC's planners have exploited the modular design of Terminal 1 to meet the contrasting demands of major network carriers, package-tour airlines operating hubs, and low-cost carriers within the same facility (Munich/Franz Josef Strauss Airport, 2002)[12]. In 2005, the multiple low-cost carriers stationed in Terminal 1 experienced a 28 percent increase in overall traffic volume, serving 12.2 % of the airports total demand.

London/Stansted also boasts a great degree of flexibility due to a modular design. Since its opening, the terminal building has been extended by the addition of two structural bays. Further extensions can continue to increase the airport's overall capacity.

Leaving Room: Providing Spare Capacity

Although modularity can allow for the rapid extension of facilities, most airports must nonetheless ensure that some spare capacity it always on hand. Given the correct level of spare capacity, this need not be considered waste, especially if the additional facilities can be shared by different customers. Spare capacity provides multiple benefits. Aside from helping to offset the effects of peaking, spare or redundant capacity mitigates the risks associated with schedule uncertainty. For instance, additional facilities can provide the space needed to cater to unexpected passenger levels in cases where airline delays (due to weather, accidents, etc.) cause unexpected shifts in traffic.

The use of swing spaces enhances this functionality. By creating sterile corridors which can be used either to connect or to separate various lounges, swing spaces permit airport operators to allocate capacity flexibly. The technology has been proven at airports worldwide; swing spaces already allow for lounges to transform from international to domestic use.

Maintaining additional capacity carries other benefits. Having extra transporters on hand, for instance, can help mitigate the losses incurred if other transporters fail. Nonetheless, airport planners must be careful to differentiate between providing for spare capacity – a real options concept – and building capacity before it is required. Whereas spare capacity provides for unforeseen fluctuations in the short term, building unneeded capacity relies on the speculation that traffic will develop in a particular manner over the long term.

5. Adapting to LCC and MAS: A Common Difficulty

In concluding the analysis of real options in airport design, it again becomes necessary to consider the low-cost carrier and multi-airport systems. The reasoning is clear: there is no question that the emergence of the low-cost carrier and of multiple airport systems has significantly impacted the air transport industry (Chapter 2). Equally important, low-cost

---

[12] Terminal 1, though modular, is not without flaws. Due to its decentralized nature, MUC is forced to operate redundant operations in each module. Terminal 2 avoids this problem by using a central structure meant to promote the use of the airport as a major European hub. Terminal 1, meanwhile, has been dedicated to supporting point-to-point traffic.

carriers and the system of airports they support have had an important effect on airport planning and design. However, the above sections show that each level of airport planning (international, national/regional, and airport level) stands to make improvements in adapting to the changing industry. Certainly, the experiences at Frankfurt/Hahn, Liverpool, and other airports worldwide drive home the benefits to be had. What remains undetermined, however, is how best to adapt airports in order to best succeed given the industry's evolution. This final section therefore seeks to address the issue from a flexibility-minded perspective.

Current Approaches: the Pitfall of Finalizing Functionality

In 2001, Michael Pitt outlined some current approaches to handling the rise of low-cost carriers at major airports for Facilities magazine (Pitt, 2001). Given the different airport requirements set forth by network and low-cost airlines, he argued, the provision of separate facilities provided the best option for airport designers wishing to ensure continued profitability. Various airports worldwide have followed this plan, including at Marseilles/Provence (MRS) and Geneva/Cointrin International (GVA), where operators opted to convert old facilities into LCC-specific terminals.

On its face, the separation of facilities appears wholly logical. In cases where the differences between low-cost carriers and network airlines are sufficiently at odds, the construction of entirely separate terminals – or even airports – can offer a simple solution. As a result, low-cost carriers can be provided with terminals specifically catered to their needs: minimal lounges and catering, simple single-story buildings, and appropriate passenger services. Further, separating terminals allows airport planners to account for design differences in terms of providing for transfer passengers, a customer not currently served by LCC but quite important to most major network airlines. Separating gates, in the meantime, can help to attract LCC by unbundling services – including air-bridges, high-class lounges, and technologically impressive passenger control desks – generally provided to national airlines. In the extreme, constructing entirely separate airports to service LCC customers can help to ensure the reduced congestion and fast-turnaround times which airlines like Ryanair demand.

Similar strategies have developed in the handling of multi-airport systems, where airport operators have sought to divide responsibilities between airports within the same region. Specialized services may be provided at each. In London, for example, Heathrow has developed as a full-service intercontinental airport while Gatwick and Luton provide for the low-fare and holiday-tour customer, respectively.

Table III Potential for resolving facilities requirement differences at same airport

Access	*Location*: current strategic direction means that low-fares airlines actively seek cheaper secondary airports to ensure minimal landing fees to maintain low fares. Ideally slots should be made available for head to head competition to the same location offering differentiated levels of service *Resolution*: two terminals
Terminal	*Ticketing*: Internet sales now dominate in the low-fares sector No significant facilities issue *Resolution*: none needed *Check in*: speed is the only issue for the low-cost carrier here The general high quality of check in facilities at BAA's airports for example are of a higher standard than necessary *Resolution*: two check in areas or two terminals Terminal services: not wanted by low-fares carriers *Resolution*: two terminals *Terminal facilities*: not wanted by low fares carriers (except toilets) *Resolution*: two terminals
Gate	*Gate facilities*: low tech required by low-fares carrier *Resolution*: two terminals *Aircraft apron access to gate*: no air-bridge to enable fast turn for low-fares carrier *Resolution*: use non air-bridged gate *Lounge*: basic standard for low-fares airline *Resolution*: two terminals *Passenger routing*: segregation of in and out passengers to provide for fast turn for low-fares carrier *Resolution*: two terminals
General	*Catering*: minimal requirement for low-fares carrier *Resolution*: none needed *Cleaning*: minimal requirement for low-fares carrier *Resolution*: none needed *Standby aircraft parking*: no requirement for low fares airline *Resolution*: none needed *Cargo/baggage*: aircraft clearance and reloading a priority for low fares carrier *Resolution*: directional. None needed

Figure 4-7: The two terminal solutions (Pitt, 2001)

This approach involves significant risks, however. As the examples of BWI and MCI illustrate, building to the specification of one particular type of airport customer can yield very negative consequences. The issue may be more pronounced when dealing with LCC, as they have demonstrated a willingness to transfer airports as necessary. As a result, the construction of separate, differentiated facilities appears to stand at odds with ensuring flexibility, a central principle of real options design. Moreover, the construction of entirely separate facilities risks cost-inefficient duplications of effort.

Seeking Similarities: Reconciling Differentiation and Adaptability

Though several observers of the air transportation industry have documented important differences in the types of airport patronized by low-cost and network airlines, the crux of flexible planning relies on the identification of similarities between apparently distinct future scenarios, customers, and stakeholders. Numerous similarities shared by LCC and NC are apparent; detailing those areas on which different carrier groups agree can therefore reveal possibilities for using real options as a means of dealing with ongoing changes in air transportation.

Overlaying the interests of major airline consortia, low-cost carriers, and airport managers – each of which operates on the airport level – reveals numerous points of agreement. Simply stated, air transportation stakeholders appear to be converging on similar airport demands. For instance, various passengers and airline types have come to demand a greater integration of transport networks. Though a common goal of low-cost carriers like easyJet, which actively invests in transportation systems near its airports; airport managers including the BAA, which operates its own rail services; and major airlines groups like the Star Alliance, which is focused on increasing the connectivity of its networks, have also pushed these initiatives. Petitions for decent (rather than extravagant) passenger facilities and simple terminals are also increasingly pervasive: while passengers still seek a minimum standard of service, even major airlines have begun efforts to reduce costs by avoiding expensive, overly ornate terminal facilities. Elsewhere, internet sales, paperless ticketing, and common user equipment are evolving into industry standards with strong support from airport stakeholders on all levels. This convergence has important implications: segmentation in the airline industry does not necessarily demand segmented gates, terminals, and airports. Developing airport facilities that can cater to different customers is far from impossible. In fact, should current trends continue, the need for separate facilities may dissipate; in either case, real options solutions can play an important role by allowing for the flexibility to serve different carriers as the need arises.

Options in Operation: A Different Approach to LCC and MAS

Given a basis of common needs shared by low-cost carriers and their competitors, it becomes possible to apply real options principles to mitigate the risks presented by industry changes. Incremental development provides one choice of interest. Seeing as low-cost carriers generally demand less complicated terminal systems, airport designers may choose to first develop terminals to low-cost standards. If flexibly designed, the facilities can then be upgraded later, as necessary. Modularity and multi-functionality can also assist in this endeavor. Modularity, for one, gives airports the option to expand and upgrade when and if requirements change. Otherwise, using multi-functional facilities and implementing swing spaces can permit airports to cater to both LCC and NC customers without requiring additional facilities, depending on peaking. This tack may prove particularly interesting for new airports uncertain about future prospects. Whereas building big initially may lead to significant waste, building smaller for low-cost carriers can minimize risk while helping to attract airlines which promote phenomenal rates of traffic growth. In fact, airport designers have begun to present new solutions along these lines[13].

Furthermore, this development standard seems well-suited to the promotion of regional economic development fostered by international and national stakeholders. The research efforts of Bonnefoy and Hansman support this point, as it shows that the entry of low-cost carriers in areas with a "secondary population basin" tended to support the development of those markets surrounding the secondary airport. More important, they showed that that growth was not limited to the LCC; rather, secondary airports with LCC patronage are capable of attracting new non-LCC service much to the benefit of the local region.

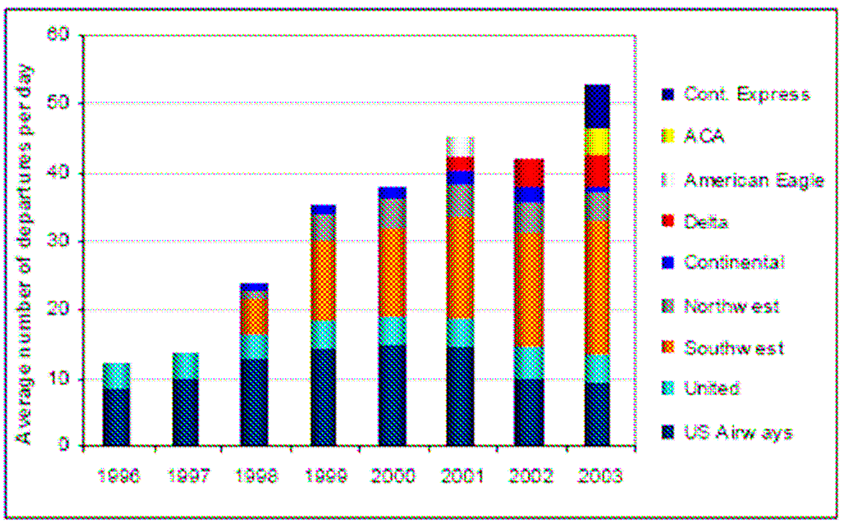


Figure 4-8: Distribution of Traffic at Manchester Boston Regional Airport (Bonnefoy & Hansman, 2004)

Indeed, the experience at airports such as Manchester Boston Regional Airport (MHT) could go so far as to suggest an "LCC-first" policy for the development of new airports. Given that the airport is built flexibly, the facility can benefit from the rapid growth rates provided by LCC while later enjoying growth in non-LCC markets.

---

[13] 3DReid Architecture, responsible in part for development at several UK airports, has designed Airspace, a flexible, modular terminal solution (Farmer, 2002). Flyport, a competing modular terminal product based on prefabrication, will be presented in October 2007 at the 16th inter airport Europe exhibition held at MUC (Flyport, 2007).

Regardless, the flexibility mantra is certainly not limited to an “LCC first” policy. Constructing airports or terminals to the specifications of network carriers while maintaining the option to convert them to low-cost service later – by removing undesired and expensive equipment and services – also minimizes risk.

Similarly, the development of multi-airport systems (MAS) can benefit from the provision of modular and adaptable airport designs. In this case, maintaining flexibility can help ensure that airports within a system can adapt to new competitive contexts by choosing to serve different customer sets.

Table 4-7 presents flexible alternatives suitable in providing for both the development of multi-airport systems and the growth of the low-cost carrier.

Table 4-7: Real Options Approaches to LCC and MAS

Time Frame	Real Options Approach	Difficulty Avoided	Related Equipment/ Actions	Value Added	Positive Examples
Current Airport Operations	Multi-functionality	Betting on traffic/customer type (BWI)	Building modular spaces	Permits reconfiguration between LCC & NC	MUC Airport Terminal 1
			Sizing gates for different aircraft	Serves varying aircraft mixes / customer types	*In Common Practice*
			Creating lounges to serve different passenger types	Allows switching between LCC & NC	
			Using swing spaces		
	Shared Spaces and Equipment	Betting on traffic/customer type (BWI)	Common User Terminal Equipment	Increases efficiency; reduces equipment	MUC Airport Terminal 2
			Centralized Facilities	Minimizes space requirements	
			Common lounges, terminals, and airports	Allows switching customers	
	Incremental Development: Build Simply First	Monument Building	Tug and Cart Systems	Reduces capital costs	DIA Airport
			Self-Propelled People Movers	Provides for future expansion	
Airport Development, Expansion, and Planning	Ensure Expandability	Capacity Constraints	Building Modular Spaces	Attracts LCC and NC	STN Airport
	Maintain Multiple Options for Airport Siting & Growth	Capacity Constraints	Landbanking	Ensures existence of LCC appropriate airfields	HHN Airport
			Maintaining Military Airfields		
	Integrated Transport Networks	Risk of underused capacity	Link airports with roads/rail to underserved areas	Attracts LCC and NC	LPL Airport
Benefits of LCC & MAS	Promote Regional Development	Increase Airline Competition	Support Passenger Choice	Attract Rapid Traffic Growth	Emphasize cost-efficiency

.

6. Finally Flexible: Real Options Solutions Reviewed

That uncertainty is an important factor in airport planning is not in dispute; however, there remain important questions on how real options planning can assist in mitigating risks. The preceding paragraphs argue that, although real options thinking is largely based on a single concept – maintaining flexibility – that concept must be marketed to different stakeholders differently, based on their individual goals and powers. The following sections drive home this point by summarizing the objectives of various airport groups and reiterating real options solutions which may be best pursued by each.

Real Options and the International Community

Although members of the international community do not necessarily exert a binding force on the specifics of airport design, their objectives and abilities are well suited to the promotion of real options. Common community initiatives such as advancing sustainable development in air transportation and encouraging the financial success of airport projects, for instance, can easily be furthered by flexible thinking. Certainly then, the overlap between international goals and the power of real options implies that option-based planning could receive significant buy-in from the international community.

Simultaneously, the influence held by international airport literature could significantly advance flexible thinking worldwide by reducing reliance on forecasts and master planning, thereby helping to mitigate expensive risks.

Table 4-8: Real Options and the International Community

Level	Real Options Suggestion	Related Actions	Difficulty Avoided	Value Added	Positive Examples
International Organizations	Fending off Forecasts: Promote new planning paradigms	Promoting scenario rather than forecast-based planning	Myth of predictability	Reduces risk of overspending Mitigates opportunity costs	SYD Airport 2nd Runway
		Promoting use of wide error ranges	Incorrect capacity planning	Increases appreciation of uncertainty	
	Moving away from Master Planning: Promote flexibility	Suggesting deferral of decisions	Building to old requirements	Permits time to survey market	AUS Airport
		Encouraging negotiable professional service agreements	Design "Lock-in"	Gives flexibility to adapt services	
	Looking to LCC and Multiple Airport Systems	Please See Table 4.7			

Real Options for Regional and National Community

Although airport planners on the regional and national levels often share the goals of their international counterparts, these stakeholders tend to enjoy increased influence over the specifics of airport development. However, they also carry the added responsibility of balancing the development of aviation with other modes of transportation as well as with social and environmental goals, thereby adding new layers of complexity and uncertainty. Moreover, national players must handle difficulties including attempting to direct airport traffic, lost opportunities resulting from under-capacity, and expensive construction well before it is needed. Fortunately, real options thinking offers several possible solutions which can be specifically catered to the needs of regional and national level policymakers. Equally important, regional and national level stakeholders are uniquely able to promote flexible planning by mandating the use of wide forecast ranges and by amending their own policies to avoid rigid master planning. Moreover, regional and national operators are likely the stakeholders most capable of advancing the use of landbanking, co-modality, and civil-military airfield conversions in order to mitigate uncertainty. Table 4-9 illustrates.

Real Options and the Airport Level Community

Finally, airport stakeholders on the "airport level," being the airport customers and decision-makers, exert the greatest influence on airport design. As a result, these groups are likely the most capable of advocating for real options thinking and the most likely to receive the bulk of its benefits. Perhaps more than any other group, it is these airport planners, managers, and customers which must buy into the flexibility concept. Fortunately for real options advocates, there is a significant overlap between stakeholder goals and real options abilities: reducing capital costs, ensuring adaptability to differing customer needs, increasing the potential of profitability, and reducing the risks of financial loss are all among the strengths of flexible planning. The airport level community, correspondingly, is uniquely able to apply real options thinking "in" project development, applying flexibility to the many detailed aspects of airport design. Table 4-10 illustrates.

Table 4-9: Real Options and the National/Regional Community

Level	Real Options Suggestion	Related Actions	Difficulty Avoided	Value Added	Positive Examples
Regional and National Organizations	Co-Modality	Developing multiple transportation systems	Dependence on only one transport alternative Capacity constraints Predicting what type of traffic will develop	Provides greater capacity and redundancy	UK/EU Transport Plans
		Integrating airports into larger transportation system	Underused Airports (YMX)	Improves surface access to airports Increases attractiveness to airlines	ARN & LHR Airports LCC Airports
	Landbanking	Purchasing tracts to support future airports	Capacity constraints: lack of new airport sites Predicting where traffic develops (YMX) Directing traffic (IAD)	Reduces land costs Ensures ability to create new capacity	SYD Airport
	Maintaining Military Airfields	Keeping military airports in operation	Capacity constraints: lack of new airport sites Predicting where traffic develops (YMX)	Maintains options for new airports	HHN Airport
		Building airports on military airfields	--	Reduces overall airport costs	AUS Airport
	Incremental Development	Using modular terminals	Monument Building (KIX/YMX)	Supports adaptability and expandability	STN Airport
		Encouraging continuous planning	Speculating on traffic growth (YMX)		DFW Airport
		Supporting market-based expansion	Misplaced/ Underused capacity (IAD)		
	Looking to LCC and MAS	Please See Table 4.7			

Table 4-10: Real Options and the Airport Level

Level	Real Options Suggestion	Related Actions	Difficulty Avoided	Value Added	Positive Examples
Airport Level	Landbanking	Purchasing land around airport	Capacity constraints: urban encroachment (LHR)	Safeguards room to grow	UPS WorldPort
	Incremental Development	Building modular facilities	Capacity constraints Limited functionalities	Aids expandability Reconfigures to meet new demands	STN Airport MUC Airport Terminal 1
		Using linear midfield terminals	Capacity constraints: unable to expand	Aids expandability	DIA Airport
		Beginning with tug and cart baggage systems	Misused/ underused capacity: built before required	Aids expandability	DIA Airport
		Beginning with self-propelled people movers		Switches on/off as needed	JFK Airport
	Looking to Share	Employing centralized facilities	Redundant operations and duplicated expenditures (KCI/MUC Terminal 1)	Gives flexibility to move traffic	MUC Airport Terminal 2
		Operating Common User Terminal Equipment		Reduces space and equipment required Enhances efficiency & speed	GVA Airport
		Sharing gates, lounges, and terminals	Uncertain Traffic Levels Demand Peaking	Benefits hubbing Offers spare capacity	MUC Airport Terminal 2
	Multi-functionality	Building modular facilities	Betting on traffic/customer type (BWI)	Reduces need for separate facilities	MUC Airport Terminal 1

CHAPTER 5: THE PORTUGAL CASE STUDY

Chapter 5 - Presents two models developed for analyzing real options in airport systems. This section also gives an introduction to Portugal, which yields a theoretical case study in the application of the real options approach at new airports.

1. Portugal Overview

Located in the southwest portion of Europe's Iberian Peninsula, Portugal is in a period of change. Having advanced an agenda for European progress (the Lisbon Strategy) during its Presidency of the European Union in 2000, Portugal now seeks to fulfill its obligations to that strategy. The Portuguese National Action Programme for Growth and Jobs (PNACE 2005 – 2008), as a result, defines a path for increasing the GDP growth rate, raising employment, and promoting economic competitiveness. In addition, the Programme commits Portugal to increasing its territorial cohesion and promoting an urban system which integrates its cities and advances the development of its more remote areas (Portugal, 2005). Though the strategies are diverse, the benefits of aviation here are clear: regional development, economic competitiveness, and national cohesion are common goals for air transport worldwide. Indeed, Portugal has placed both aviation and maritime transport within its overall development strategy.

Figure 5-0: Portugal

<u>The Role of Air Transport</u>

Tourism

Aviation already plays a major role in Portugal's economic advancement. A favored destination for Northern European vacationers, Portugal benefits significantly from its aviation industry, which directly accounted for 7.3% of employment and 6.4% of GDP in 2006; with tourism related business accounted for, this number increases to 17.7% of employment and 15.5% of GDP (Economist, 2007).

Competitiveness Strategy

Aviation further plays an important role in Portugal's competitiveness initiatives and development strategies. Aside from contributing to tourism growth in lesser developed regions, air transport and its sister systems (high speed rail, maritime transport) are each central to overall Portuguese growth. The Programme for development states this objective clearly: in order to overcome its "peripheral" geographical position in relation to Europe, Portugal intends to exploit its central location (between Africa, Northern Europe, and the United States) and to promote its east-west and north-south maritime and air routes (Portugal, 2006). Further, Portugal seeks to develop airline hubbing within its territory by advertising its position in relation to major Northern European cities and its relative lack of airspace congestion. Together, these initiatives give Portugal the opportunity to better integrate with Europe, promote internal growth, and increase its overall economic attractiveness worldwide.

Lisbon Portela Airport

Opened in 1942, Lisbon/Portela Airport (LIS) – which is operated by the fully state-owned subsidiary ANA – has long served as Portugal's premier international gateway. As such, LIS has provided an important impetus for development in the greater Lisbon area. The nation's largest airport, Portela operates two runways which serviced approximately 12 million passengers in 2006.

The continued growth of Lisbon/Portela, however, is capacity limited. One of the few European airports located within a major city, LIS is now landlocked by urban development. With a passenger growth rate of 11%, it will soon achieve full capacity and, despite ongoing expansion, begin to experience difficulties as a result of too-high demand by 2009 (Chevalier, 2005). As a result of Portela's rapid development, many corners within Portugal have aggressively pushed for a major new Lisbon-area airport.

<u>The New Lisbon International Airport</u>

Goals

The development of the New Lisbon International Airport (here referred to as NLA) augurs many benefits for Portugal as a whole. Aside from providing for the expansion of the Portuguese passenger market, the airport's development is intended to help increase Portugal's presence worldwide. According to the Novo Aeroporto S.A. (NAER), the state-created company charged with preparing decisions regarding the new airport, the new facility will also help to bring Portugal into the center of the European air transport network and promote Portugal's importance as a transcontinental connection hub and further promote regional development (NAER, 1982). Moreover, the new airport – intended to be part of a multi-modal link between Portugal, Spain, and Eastern Europe – may well grow into a major hub able to compete with Madrid for traffic.

Description and Stakeholders

As Portugal's new primary access point, the New Lisbon International Airport is expected to cost some US $4.8 billion (€ 3.6 billion) before accounting for the addition of the highways and high speed rail links that will be required to provide better connectivity

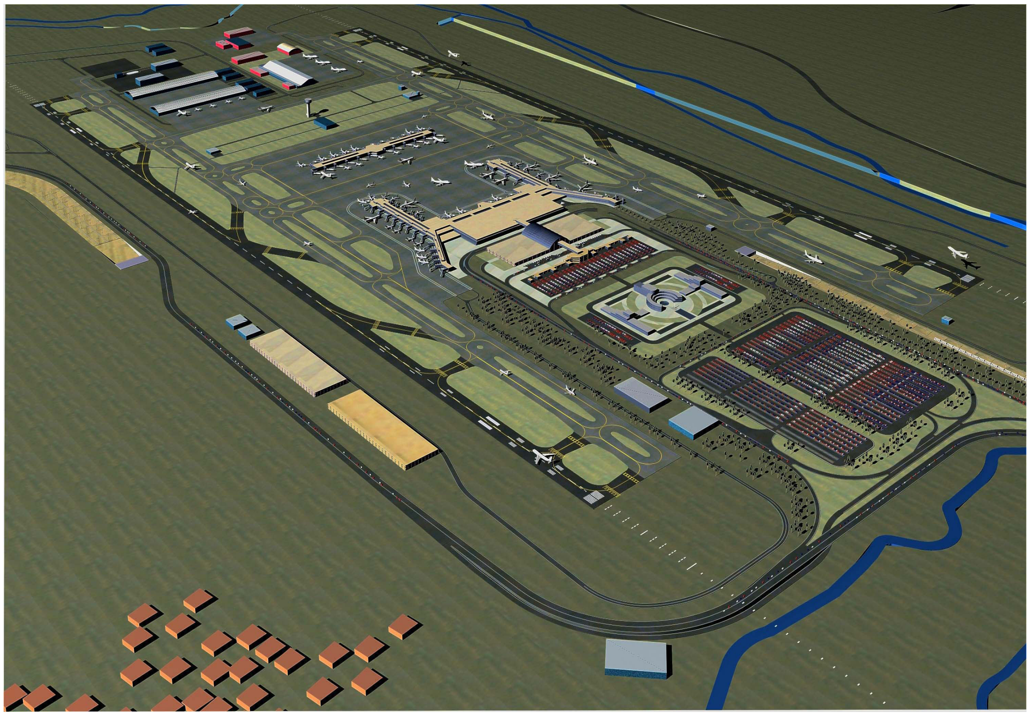


Figure 5-0: Ota New Lisbon Airport Artist's Depiction

to the capital (Lopes, 2005). With a capacity of 40 million passengers per year on its two runways, the new airport does not come at a low cost. However, if current projections of 33 million passengers served per year by 2039 (Lopes, 2005) are correct, the airport will offer significant benefits.

As a result, the stakeholders in the project are numerous. Certainly, the airport offers an exceptional development opportunity for its region and for Portugal as a whole. The list of beneficiaries is not limited: aside from creating a projected 50,000 new direct and indirect jobs, the new airport bodes well for Portuguese construction companies like Mota-Engil, which has seen its stock price surge partially on positive news regarding the airport (BPCC, 2007). Further, the Portuguese government and the wider European community are heavily invested in the airport, which is expected to be financed partially by the EU and supported by a loan from the European Investment Bank as part of its initiative to develop the Trans-European Transportation Network. In addition, acquiring tender on the new airport weighs heavily on Portuguese business and politics, as the winning consortium is expected to gain control of the ANA, the national body now directing the bulk of Portuguese air transport. As a result, the interest of the stakeholders in the new airport is extraordinary.

Uncertainty

Despite the interest in Lisbon's new airport, the project is certainly not without uncertainty, however. Indeed, a new challenge has recently arisen to the location of the second airport, with the private Confederation of Portuguese Industry (CIP) supporting an abandonment of one site in favor or another.

As a second airport, NLA also faces an important degree of uncertainty regarding its ability to compete with and eventually replace Lisbon/Portela. Although the government currently plans to close LIS and to transfer its traffic, the difficulty of governments in closing old airports and redirecting traffic is well documented. Noted examples include Paris Orly (ORY), where the forced competition with Paris Charles de Gaulle (CDG) cost the French government a considerable sum of money, and Osaka International Airport (KIX), which was intended to replace the still thriving Osaka Itami (ITM). The effect of privatizing Portugal's airport authority, ANA, remains unknown.

Further, Portugal is certainly not immune from the effects of larger aviation trends such as the growth of low-cost carriers (LLCC) and the unsteady performance of national and network air transport providers (NC). Within the past year, for instance, Portugal's largest airline (TAP) purchased the nation's second largest carrier (Portugalia), pending government approval. In addition, low-cost carriers have been increasing their activity in Portugal, with Ryanair, easyJet, bmibaby, and others servicing Portuguese locations. The continued growth of LCC in Europe therefore raises important questions for the development of a new Lisbon airport, as LCC have tended to have much different design requirements when compared to other airlines. Further, although easyJet and Ryanair currently provide service to multiple Portuguese destinations (including easyJet at LIS), their development at the New Lisbon International Airport cannot be guaranteed, especially in light of proposals to build a new LCC-specific Portuguese air center, LCC opportunities elsewhere, and the development of facilities at Badajoz, just across the border in Spain.

Certainly, the immense potential impact of uncertainties associated with the New Lisbon International Airport makes it an interesting case for the study of real options. Moreover, analyzing an Ota-like facility provides an opportunity to demonstrate the value of flexibility in airport design. As a result, this thesis' final case study is designed with the New Lisbon International Airport in mind.

2. Modeling the New Airport

While operating within an intricate system of external transportation types, airlines, passengers, local community members, and various layers of economic and political decision-making, each airport also exists as a complex system unto itself. The airside which supports aircraft, for instance, can be broken down into several distinct parts: air traffic control, paved thoroughfares, fueling stations, cargo facilities and so forth. Paved thoroughfares can further be subdivided into the runways which provide for take-off and landing and the set of taxiways which facilitate other aircraft movements and give access to service vehicles participating in aircraft loading, fueling, service and maintenance. The airport landside is no simpler. Rather, the landside may be construed to consist not only of airport terminals but also of the parking garages, roadways and other transportation links which connect the airport to its region. Further subdivided, the airport terminal provides shopping areas, customs and immigration centers, baggage handling, internal passenger transportation, waiting areas, and a slew of other necessities. As a result of this complexity, any model attempting to simulate all airport operations fully can easily become both large and unwieldy. Within the context of this thesis, then, a simpler paradigm is required.

The models described in this chapter therefore focus on the centers of the airside and landside: the terminal or passenger buildings (landside) and the runway (airside). Both structures are at the core of airport operations and represent significant airport cost expenditures. Further, they yield several opportunities for flexible planning. The terminal and runway models, therefore, can be explored in order to reveal the strengths of real options thinking and to support the development of curricular material.

The Airside Runway System

Airport runways perform an immensely important function: they are the means by which an airport – otherwise simply a collection of buildings – takes meaningful form. Runway design and certainly the number of runways provided are therefore of principal importance, especially given that runways are quite often the limiting element in determining how many passengers an airport can serve (Reynolds-Feighan,1999) and, consequently, the size of the airport's revenue streams. Given this, an appropriately constructed runway infrastructure must be correctly sized to serve its airport's projected traffic levels: a runway system that is incapable of supporting the number of aircraft movements required per year represents a lost opportunity for the entire airport system. Conversely, with some runway prices rising above US $600 million (BWI), building and maintaining an underused runway represents an expensive waste.

In this sense, evolution of demand is the main uncertainty involved in runway planning. By and large, other factors are of secondary importance. Uncertainty about the type of customer (LCC or NC), for instance, is less critical in this area because all customers are generally constrained to using the same runways. The New Airport Runway Model, therefore, focuses solely on volatility of demand. A binomial lattice method is employed to model this volatility. The lattice method is well-suited to this purpose as it easily replicates the growth of a single factor so long as that factor tends to have a constant growth rate and volatility over the period of interest. Airport planners can reasonably assume this to be true of passenger traffic.

The Landside Passenger Building

Compared to runway design, several more decisions and uncertainties affect the creation of a successful terminal. For instance, runway planners need only consider how many runways must be constructed in order to service a given level of total traffic. Terminal design, conversely, must account not only for total traffic flow but also for traffic type (i.e. low-cost or network), and passengers served (i.e. tourist, business, international, etc). Terminal buildings built to the specifications of one network carrier may not be well-designed to serve another network carrier; also important, such terminals almost certainly will not be designed for servicing the low-cost passenger. As a result, terminal planning is subject to new LCC driven uncertainties as well as to overall demand volatility; models of terminal activity, therefore, must be able to represent these multiple uncertainties and the set of very different options needed to combat them.

In this case, the binomial lattice tends to become unsatisfactory. Decision trees, however, are quite capable of modeling the development of uncertain terminal-related parameters. Aside from allowing planners to consider multiple unknown factors, decision trees permit planners to consider the effects of sudden changes such as a switch from serving network to low-cost traffic. Further, trees can simulate the large range of alternatives which may become available to the airport planner at different periods in time.

3. The New Airport Runway Model: Inputs and Results

Given information on average passenger growth rate, volatility of traffic, expected aircraft mix, and airport revenue streams, the New Airport Runway Model seeks to reveal when best to construct additional runways at a new facility. By giving consideration to probabilistic trends in demand growth, the model calculates the value of the airside runway system as a function of when and how much runway capacity, in terms of aircraft movements per year, is constructed. Further, the model compares various building strategies: building only one runway, building two runways initially, or building one runway initially and supplementing it with a second runway at a later date. Details regarding the underlying operation of the runway model, including a full list of inputs, equations, and assumptions are available in Appendices A1 and A2. The following pages present the application of the runway model to a theoretical representation of the New Lisbon International Airport. Results are meant to inform the Runway Model processes rather than to provide detailed advice on the construction of any particular airport.

Traffic Development

The New Airport Runway Model requires data on the expected development of passenger demand in order to populate a table of possible traffic levels over the assumed period of interest, twenty-five years. Relevant information includes starting demand, average growth rate, and the standard deviation associated with sample passenger data. Given that this information is unavailable for airports that have yet to be constructed, planners may therefore seek sample data from other, similar facilities worldwide.

Observed Passenger Data						
				Default Value	[ ]	% of S
Initial Demand	*S*	=	6,000,000	6,000,000	pax	
Standard Deviation	*D*	=	15.90%	15.90%	%/yr	
Average Growth Rate	*R*	=	7.10%	7.10%	%/yr	

Figure 5-1: Sample Data on Traffic Growth

Although Appendix A2 provides information on the derivation of the data used, Figure 5-3 presents the default traffic inputs simply. While it is assumed that the New Lisbon International Airport will provide for one-half of the current traffic at Portela in its opening year, information regarding average growth rate and demand volatility derives from representative years at Dulles International Airport (IAD). These inputs nearly simulate forecasts that the New Lisbon International Airport, if opened in 2017, will serve 33 million passengers by 2039: the model predicts an expected demand of 32.6 million passengers by that year. However, it should be noted that these inputs may be overly optimistic; airports within a secondary airport system rarely start off carrying 50% of total traffic to the region.

Revenue Streams

In order to evaluate various runway sizes and development strategies, the New Airport Runway Model assumes that revenue is the primary benefit accrued from runway construction. As a result, the model focuses on comparing the returns on investment of various runway development strategies. One important simplification should be noted. In an attempt to avoid conflict with other the New Airport Terminal Model, which accounts for all fees paid by the airplane passenger, the Runway Model only accounts for the fees charged to the airline company for normal runway use. Although the model can be expanded to overcome this limitation, its current focus is on airplane landing and parking fees.

As a result of its costing structure, the Runway Model requires detailed information on fees as meted out based on aircraft weights. Sample data used in the simulation presented here derive from Cardiff International Airport (CWL) in the United Kingdom.

Revenues Streams by Aircraft Weight

MTOW min [mt]	MTOW max [mt]	Landing Fees [$/mt]	Parking Fees [$/24 hrs]
0	25	31	205
25	200	34	308
200	*max*	21	513

mt = metric tonne; parking fees accrued per 24 hrs or part thereof
Default values stored in Entries B (Default)

Figure 5-2: Sample Data on Aircraft Fees

The Runway Model also requires an aircraft mix in order to determine the number of aircraft movements required to service passenger demand in a given year, as bounded by the maximum capacity of runway system. These calculations, along with data on average fees, then translate into a value for total revenue.

Aircraft Mix				
	Avg. Capacity [pax]	MTOW [mt]	% Movements [% Total]	Revenue/ Movement [$]
B737-500	115.0	52.6	20.00%	$342.49
A320-200	162.0	73.9	30.00%	$342.49
B757-200	190.0	109.3	20.00%	$342.49
B747-400	382.0	398.3	30.00%	$533.53
			100.00%	

Default values stored in Entries B (Default)

Figure 5-3: Sample Data on Aircraft Mix

Runway Capacity and Costs

For the purpose of this example, it is assumed that airport designers plan to install two runways of the same capacity, expressed in terms of aircraft landings per year, where the total number of aircraft landings is assumed to be one-half of all aircraft movements. The maximum annual number of landings per runway selected, 95,000, correlates roughly with serving 21 million passengers annually, given the assumed aircraft mix. Using these parameters, the model assumes that the runways at the New Lisbon International Airport operates at a level similar to those at London Stansted (STN), where one runway caters to nearly 24 million annual passengers.

For the purposes of the model, each runway costs US $200 million each, paid in equal increments over twenty-five years after the runway becomes operational. Runway operating costs are set at US $3 million per year each.

Whereas it is logically assumed that Runway 1 opens during the first year that the airport serves traffic (Year 1), there is no default value for the year that the second runway comes into operation. Rather, the model is allowed to make that determination.

Runway 1			Default Value	[ ]
Period Operationalized	*a*	1	1	yr = 1
Maximum Landings	*b*	95,000	95,000	#
Capital Costs (CC)	*c*	200,000,000	200,000,000	$
Payback Time (CC)	*d*	25	25	yr
Operating Costs	*e*	3,000,000	3,000,000	$

Runway 2			Default Value	[ ]
Period Operationalized	*a*	1	1	0 < yr < 25
Maximum Landings	*b*	95,000	95,000	#
Capital Costs (CC)	*c*	200,000,000	200,000,000	$
Payback Time (CC)	*d*	25	25	yr
Operating Costs	*e*	3,000,000	3,000,000	$

Figure 5-4: Sample Data on Runway Construction

<u>Model Results and Analysis</u>

Incremental Development: When to build

The Runway Model provides an important test for the concept of incremental development. This results from the model's ability to choose the best possible year to construct a second runway as a function of hypothetical probabilistic traffic growth and runway capacity. The model provides advice on the best year to build either in terms of maximizing net income or in terms of maximizing passengers served. As Figure 5-7 illustrates, maximizing the total runway revenue in the theoretical scenario modeled here would require bringing a second runway online in Year 18.

Conversely, a second runway would not be required to serve all passengers until Year 9 even if demand grew at the fastest possible rate during those years, which – according to the model – occurs with only a 7% probability. Given this hypothetical situation, it is therefore clear that constructing both runways early on and providing for more capacity than needed may lead to unnecessary waste.

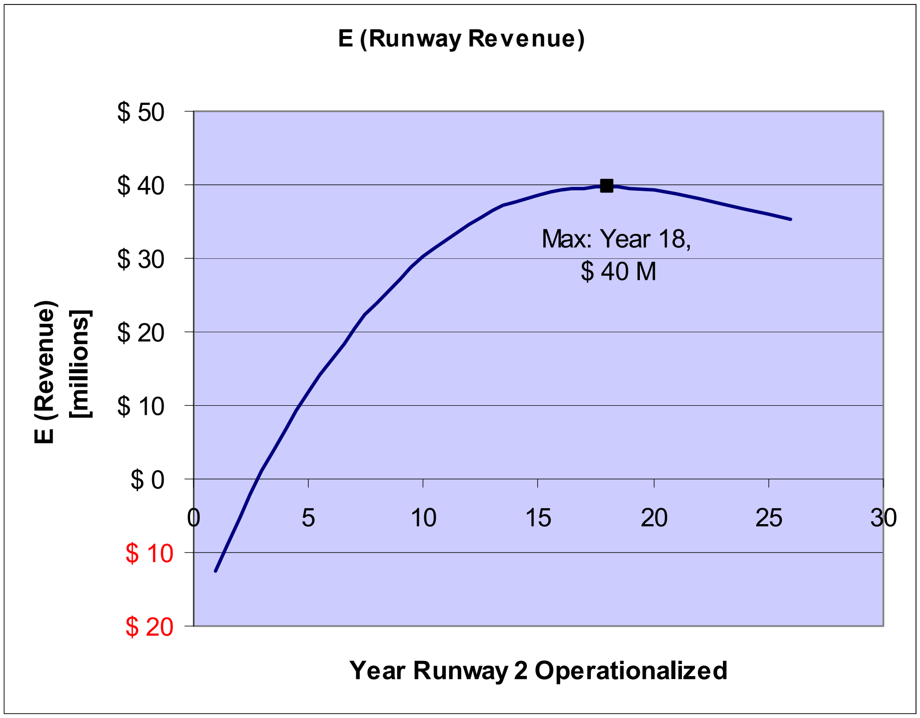


Figure 5-5: New Airport Runway Model - Maximizing Net Income

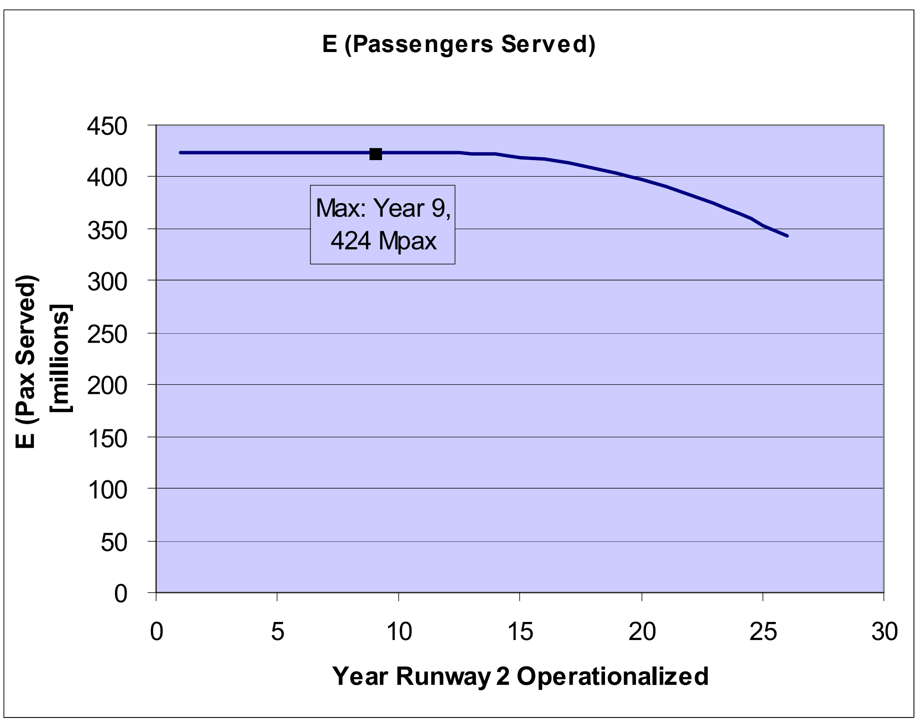


Figure 5-6: New Airport Runway Model - Maximizing Passengers Served

The above conclusion does not however obviate the benefits of a second runway. Rather, constructing a second runway can increase the overall value of the airport runway system. However, due to the additional expense, there is also a greater downside risk. Figure 5-9 presents a value-at-risk/gain graph comparing the decision to build only one runway and the decision to build two runways initially. The values presented represent net income in Year 25 alone in Year 25 dollars[14].

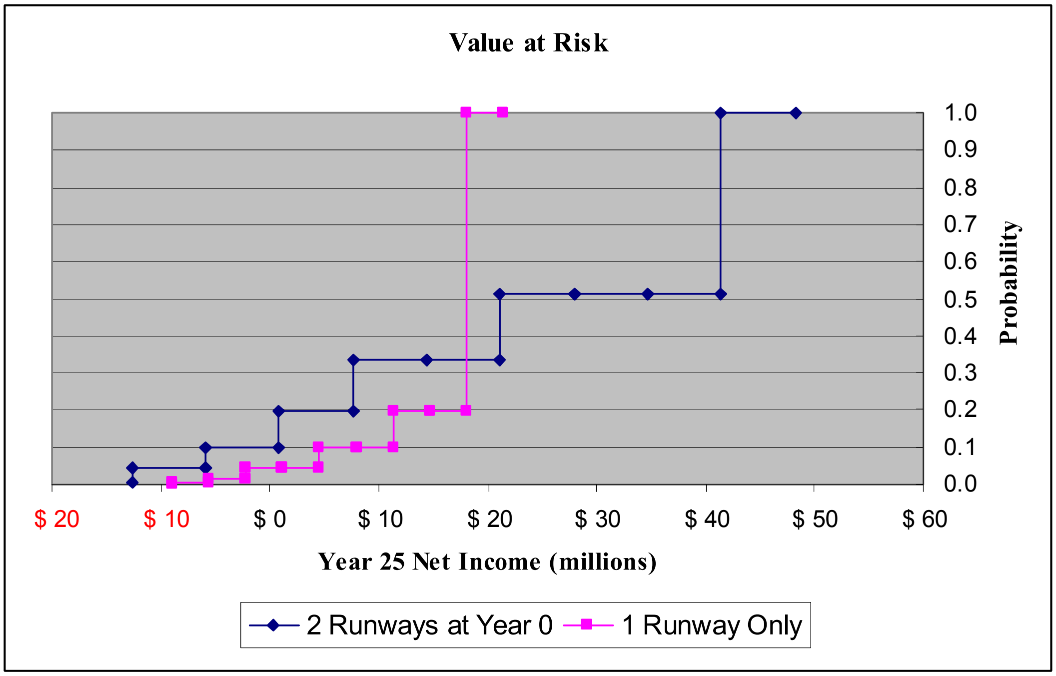


Figure 5-7: New Airport Runway Model - Value at Risk in Year 25 (Year 25 dollars)

Deferring Decisions

Whereas Figure 5-7 gives the best year to build based on the total range of traffic growth possibilities, it is useful for airport planners to track possible demand on an individual, per year basis. This allows planners to choose how to develop based on actual rather than forecast events. Figure 5-10 provides a small sample of the binomial lattice showing passenger traffic data, as explained in Appendix A1.

[14] Although it is possible to create the value-at-risk graph for the total airside value over twenty-five years, this calculation would overwhelm the computational capabilities of Microsoft Excel© with over 17 million unique possibilities, given 1 year periods. Viewing the value-at-risk in Year 25 alone, however, is still mildly informative. Were the full twenty-five year period considered, the downside risks would be far greater. Of course, the upside potential would be somewhat increased as well.

Year 1	Year 2	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 24	Year 25
6,000	7,034	21,299	25,097	29,422	34,493	40,438	47,407	55,576	65,154	232,470	272,533
	5,118	15,576	18,261	21,408	25,097	29,422	34,493	40,438	47,407	169,146	198,296
		11,333	13,287	15,576	18,261	21,408	25,097	29,422	34,493	123,071	144,281
		8,246	9,667	11,333	13,287	15,576	18,261	21,408	25,097	89,547	104,979
		6,000	7,034	8,246	9,667	11,333	13,287	15,576	18,261	65,154	76,383
		4,366	5,118	6,000	7,034	8,246	9,667	11,333	13,287	47,407	55,576
		3,176	3,724	4,366	5,118	6,000	7,034	8,246	9,667	34,493	40,438
		2,311	2,709	3,176	3,724	4,366	5,118	6,000	7,034	25,097	29,422
		1,682	1,971	2,311	2,709	3,176	3,724	4,366	5,118	18,261	21,408
			1,434	1,682	1,971	2,311	2,709	3,176	3,724	13,287	15,576
				1,224	1,434	1,682	1,971	2,311	2,709	9,667	11,333
					1,044	1,224	1,434	1,682	1,971	7,034	8,246
						890	1,044	1,224	1,434	5,118	6,000
							759	890	1,044	3,724	4,366
								648	759	2,709	3,176
									553	1,971	2,311
										1,434	1,682
										1,044	1,224
										759	890
										553	648
										402	471
										293	343
										213	250
										155	182
											132

All values in thousands of passengers

Figure 5-8: New Airport Runway Model – Sample Traffic Development

Year 1	Year 2	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 24	Year 25
$66,643	$86,486	$270,297	$290,600	$314,994	$329,601	$329,283	$319,034	$304,554	$91,199	$48,181
	$44,767	$216,839	$236,944	$252,800	$270,636	$292,278	$303,861	$300,221	$91,199	$48,181
		$158,717	$180,398	$200,750	$218,306	$231,310	$245,973	$264,059	$91,199	$48,181
		$105,337	$125,008	$144,810	$163,993	$181,485	$195,791	$205,127	$91,199	$48,181
		$60,617	$77,056	$94,176	$111,599	$128,766	$144,871	$158,790	$91,199	$48,181
		$25,186	$38,359	$52,336	$66,930	$81,845	$96,641	$110,687	$90,349	$48,181
		$1,901	$8,448	$19,549	$31,311	$43,581	$56,116	$68,555	$70,890	$44,741
		$22,116	$14,020	$5,283	$4,053	$13,906	$24,141	$34,549	$47,610	$27,203
		$36,967	$30,577	$23,654	$16,221	$8,323	$43	$8,491	$38,511	$24,090
		$47,794	$42,655	$37,071	$31,049	$24,616	$17,821	$10,749	$23,038	$14,979
			$51,444	$46,833	$41,839	$36,471	$30,758	$24,751	$11,699	$8,223
				$53,937	$49,689	$45,097	$40,171	$34,939	$3,448	$3,308
					$55,401	$51,373	$47,020	$42,352	$2,555	$268
						$55,940	$52,004	$47,746	$6,923	$2,871
							$55,630	$51,670	$10,101	$4,764
								$54,525	$12,414	$6,142
									$14,096	$7,144
									$15,321	$7,873
									$16,211	$8,404
									$16,859	$8,790
									$17,331	$9,071
									$17,674	$9,275
									$17,924	$9,424
									$18,105	$9,532
										$9,611

All values in thousands of dollars.
All values in present dollars for that year.

Figure 5-9: New Airport Runway Model - Sample Airside Value

Each cell in the lattice represents a different possible level of traffic; earlier years have fewer possibilities than later ones. Meanwhile, lower cells represent less optimistic demand states and therefore reduced cash-flow. Those cells in which a second runway is required to satisfy total traffic are presented in red. Figure 5-11, similarly, gives the lattice valuing the airside system. Those cells in which the probability of future revenue growth justifies the construction of a second runway are presented in green. Even given the highest possible growth rate – as indicated by the top row of cells – opening a second runway would not maximize revenue until Year 11.

A comparison of Figures 5-10 and 5-11 provide the argument for incremental development and deferring decisions. The markers showing in which state to open a second runway do not match in the two Figures, signifying that high traffic in one year does not necessarily suggest that a second runway ought to be opened; poor traffic development in the following years can still lead to expensive waste if demand falls off. Having the ability to defer construction decisions until continued growth is more likely is therefore quite useful. In the hypothetical scenario presented, maximizing expected profit even with the best possible rate of traffic growth (the top row of cells) requires that a new runway is not put into operation until a full two years after it first becomes needed.

Viewed differently, deferring decisions allows planners to determine what "demand state" has occurred before choosing to build. If airport operators find traffic levels to be at the best possible position in Year 11, it makes sense to open a second runway. However, if in the worst possible position, a second runway would only increase losses. Making the decision to build without this knowledge is certainly quite risky.

Option Value

Given the defined framework, the lattice model is capable of calculating the value of the option to build a second runway. Two options are present: the option to build at all and the option to defer the decision on when to build. This determination is based on the difference in earnings with and without the option.

Table 5-1: New Airport Terminal Model - Sample Runway Worth (Expected Net Present Value)

Model Run Results		
Value | 1 Runway Only	$ 58,930	[k$]
Value | 2 Runways at Year 0	$ 12,466	[k$]
Value | Option to Build	$ 66,643	[k$]

Without the option to build a second runway, the airport runway system in this illustrative but not representative example sees a net gain of US $59 million in net present dollars over twenty-five years. Building two runways at once, however, results in a hypothetical loss of over US $12 million. Again, this result shows the benefits of incremental development. Premature investment carries unnecessary costs which are not likely to be offset by additional traffic. Given this data, the airport planner can take into account economies of scale. Scale effects would have to provide US $71 million in savings in order to make building two runways at once worthwhile.

The value of the option to build a second runway (given only one initial runway) is the difference between the value of having only one runway and having the option to construct a second. In this case, the value of the option is US $8 million. Higher initial traffic levels or increased rates of traffic growth, however, could significantly increase this figure.

4. The New Airport Terminal Model: Evaluating Real Options

Like the Runway Model, the New Airport Terminal Model provides a method for evaluating various decision paths regarding the construction of a new airport. However, the Terminal Model carries benefits over its counterpart in that it exploits the additional freedom provided by decision tree modeling by considering multiple, discrete uncertainties and alternatives over two periods. Conversely, the model is subject to the limitations of decision trees, namely that its accuracy depends on the ability of the user to correctly determine the probabilities associated with each chance event. As before, all results presented are wholly dependent on user input data and are therefore theoretical.

Introduction to the New Airport Terminal Model

The New Airport Terminal Model decision tree considers two major uncertainties. First, it considers the uncertainty concerned with the changing nature of European aviation by evaluating the possibility that low-cost carriers, rather than network carriers, may dominate an airport's function. The model assumes that this is the primary uncertainty within the first ten years of airport operation. Second, the New Airport Terminal model considers the effect of traffic volatility in the overall passenger market by investigating three distinct possibilities: high, medium, or low growth. This uncertainty is assumed to dominate for the rest of the period of interest, fifteen years. Given information on the probabilities associated with LCC dominance and of low, medium, and high growth, the terminal model can then be used to highlight best paths with regards to the sizing of airport terminal buildings for the LCC and NC customer.

The Terminal Model operates by providing a two-stage decision process. By default, planners select whether or not to build primarily for low-cost carriers (Big LCC) or for network carriers (Big NC) in the first stage, Period I. A third alternative (Build for Both) calls for a smaller combination of the latter two choices. "Build for Both" allows the user to determine the value of not gambling with what type of traffic is most likely to develop.

The second stage, Period II, starts after year 10. In this stage, the planner has the opportunity to make decisions on increasing the airport size. The airport operator may either choose to increase airport size by large (Build Big) or small (Build Small) increments. The superior decision, of course, depends on the level of growth experienced during the remaining fifteen years analyzed by the model. Figure 5-12 provides a quick illustration, given that the decision has been made to build for network carriers. Appendices A1 and A2, however, describes the evolution of the basic terminal model in significant detail.

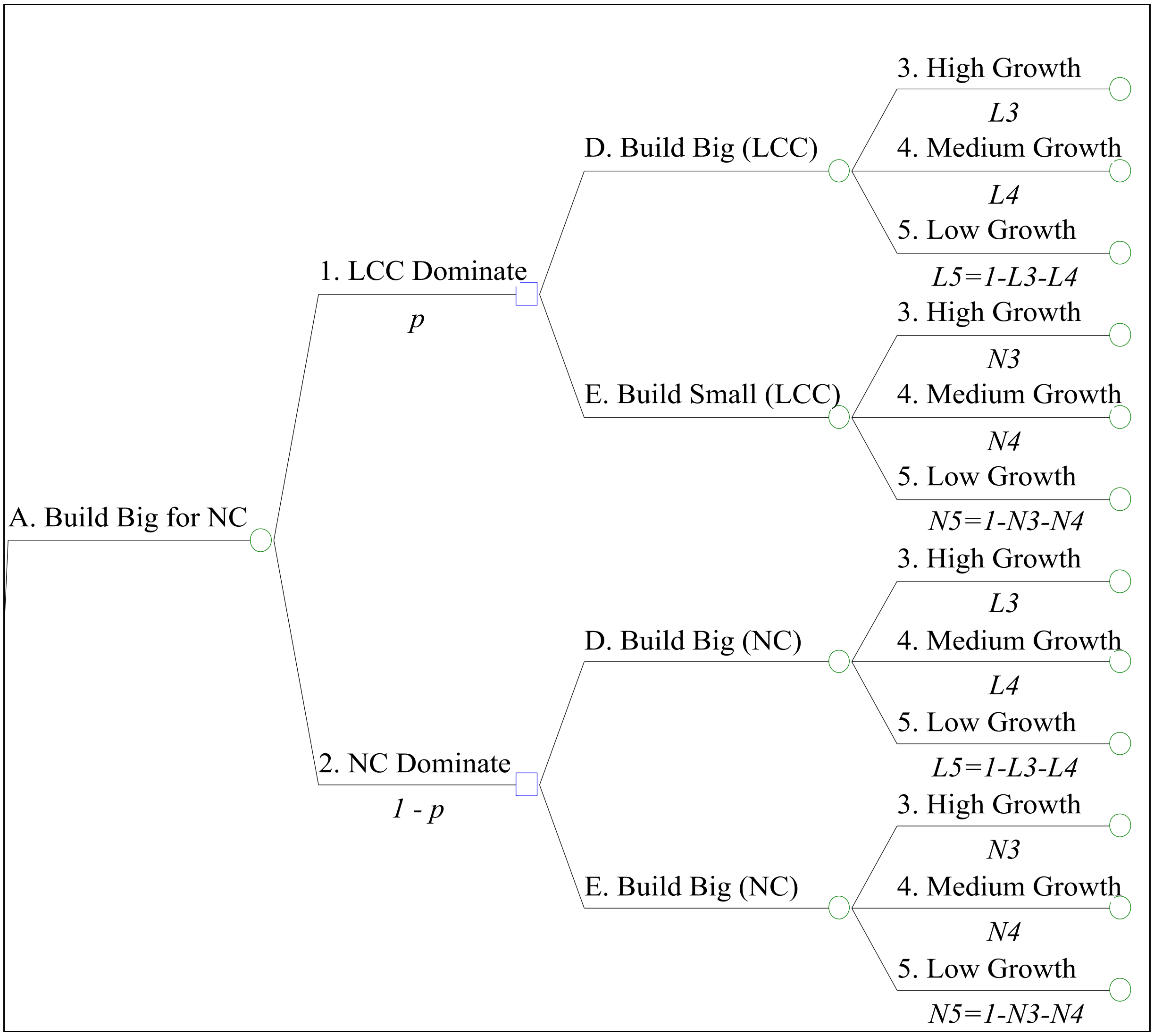


Figure 5-10: Decision Tree | Build Big for Network Carriers

<u>Real Options Evaluation</u>

Before exploring more complex alternatives for constructing new airports, it is possible to exploit the Terminal Model in order to demonstrate the value of multiple real options concepts directly. This section provides the results from analyses designed to evaluate different real options methodologies. An examination of the New Lisbon International Airport using hypothetical data immediately follows. Source information for the data used in each analysis, the appropriate inputs into the Terminal Model, and the full data retrieved are available in the Appendix A5.

Deferring Decisions

Deferring decisions regarding development until absolutely necessary is a prime tenet of real options thinking. The strength of this concept lies in ensuring the availability of different alternatives during a project's life-cycle; further, it minimizes risk by giving planners the opportunity to gather additional information on uncertain events. The two-stage decision tree in the New Airport Terminal Model can allow for this concept to be explored within the airport context.

In order to demonstrate the value of deferring decisions, the analysis described below – wherein a hypothetical airport is required to serve 20 million passengers – was performed. According to plan, the airport is completed in two phases. First, a terminal providing capacity for 10 million annual passengers for either network or low-cost carriers is opened at the beginning of the first year. A second terminal is completed in the 10th year.

Table 5-2: Deferring Decisions Evaluation – Two Strategies

		Planners With Option	Planners Without Option
Period I	**Capacity Provided (pax)**	10 million	10 million
	Customer Served	LCC or NC	LCC or NC
Period II	**New Capacity (pax)**	10 million	10 million
	Customer Served	LCC or NC	NC

Two strategies, displayed graphically in Table 5-2, are compared. In the first, planners are incapable of deferring decisions regarding the structure of the 2nd terminal. Rather, Terminal 2 must be constructed to serve the continued growth of network carriers at the airport. A second strategy, however, permits planners to defer decisions on the construction of the second terminal. In this case, planners are given additional time to monitor competition between low-cost carriers and network airlines in the hypothetical region. As a result, designers can ensure that the terminal opened in Year 10 will serve the correct customer group.

By running the model twice to compare the results of the two strategies – as explained in Appendix A5 – it becomes apparent that the ability to defer the decision on how to construct can reduce the downside risks associated with airport development. Figure 5-13 illustrates.

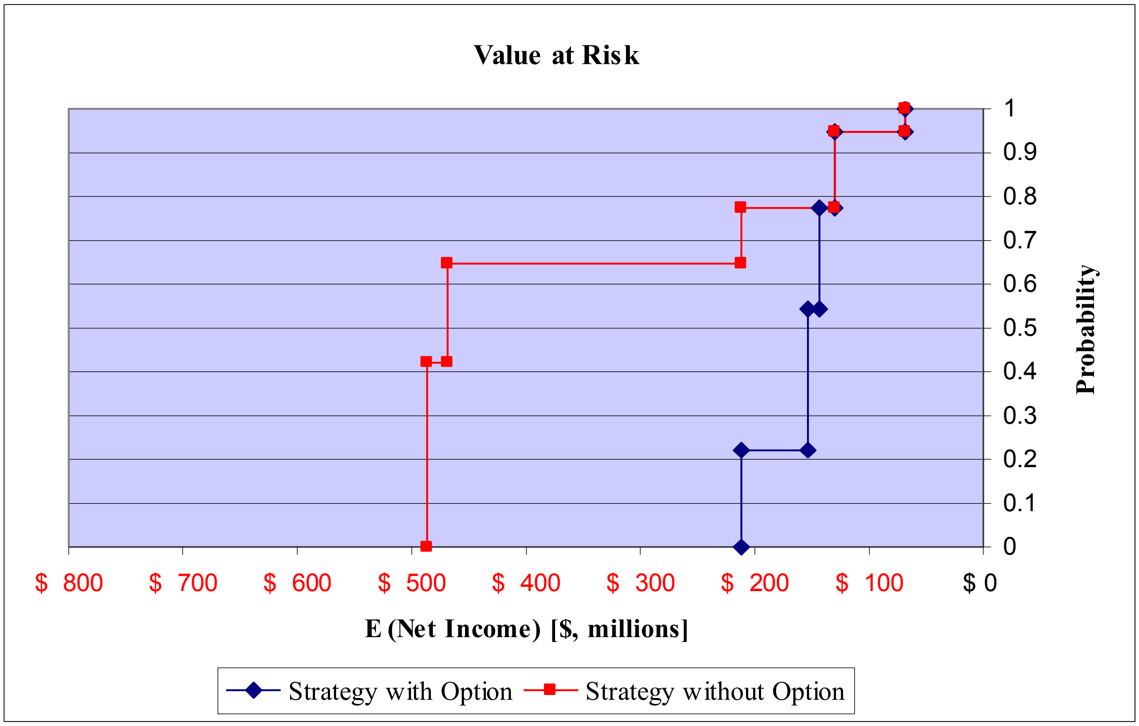


Figure 5-11: New Airport Terminal Model - Deferring Decisions can reduce Downside Risk

Multi-functionality: The Right to Switch

Outside of deferring decisions, other design strategies may be used in order to maintain flexibility. Providing for the multi-functionality of a particular system, for instance, can help to counter uncertainties concerned with changing requirements. Within the context of hypothetical airports dealing with the changing traffic types, multi-functionality can provide an important means of allowing planners to determine which customers are served during specific periods of an airport's lifetime. Constructing a terminal facility with the ability to switch facilities from LCC use to NC use is one interesting example.

Table 5-3: Deferring Decisions Evaluation – Two Strategies

		Planners With Option	Planners Without Option
Period I	**Capacity Provided (pax)**	10 million	10 million
	Customer Served	LCC or NC	LCC or NC
Period II	**New Capacity (pax)**	5 million switched or No change	No change
	Customers Served	LCC, NC or Both	No change

As before, it is possible to test for the value of building multifunctional terminal spaces by applying the New Airport Terminal Model to a hypothetical situation. In this scenario, an airport designed to serve 10 million passengers is considered. As in the study of deferring decisions, planners are given the ability to "place bets" on which customer to serve (LCC or NC) during the first ten years of airport operation. However, in this case, multi-functional spaces are used. The terminals therefore provide for limited switching between carrier types; at the beginning of Period II, one-half of the terminal capacity may be reallocated to serve another customer type. For instance, if the original terminal is built to LCC specifications but LCC do not experience significant growth over the first decade of airport operation, capacity for 5 million passengers may be reassigned to serve network carriers.

According to the investigation's results – which of course depend on the theoretical default values input in the New Airport Terminal Model – several situations exist in which planners should consider switching capacity, assuming that switching is costless. Table 5-4 shows that planners should switch capacity under two circumstances: if the first terminal was constructed for NC customers but LCC became dominant (A1) or, alternatively, if the first terminal was built for LCC customers and NC became dominant (B2). No switching is required otherwise.

Table 5-4: Multi-functionality Evaluation – When to Switch

	A1	A2	B1	B2
E(NPV) [k$]	$215,977	$67,837	$112,885	$43,184
Best Choice	D	E	E	D
Best Choice	Switch (NC to LCC)	No Change	Switch (NC to LCC)	No Change

Because it mitigates the dangers associated with predicting the type of customer served, multi-functionality reduces the risk of downside loss, as shown graphically in Figure 5-14.

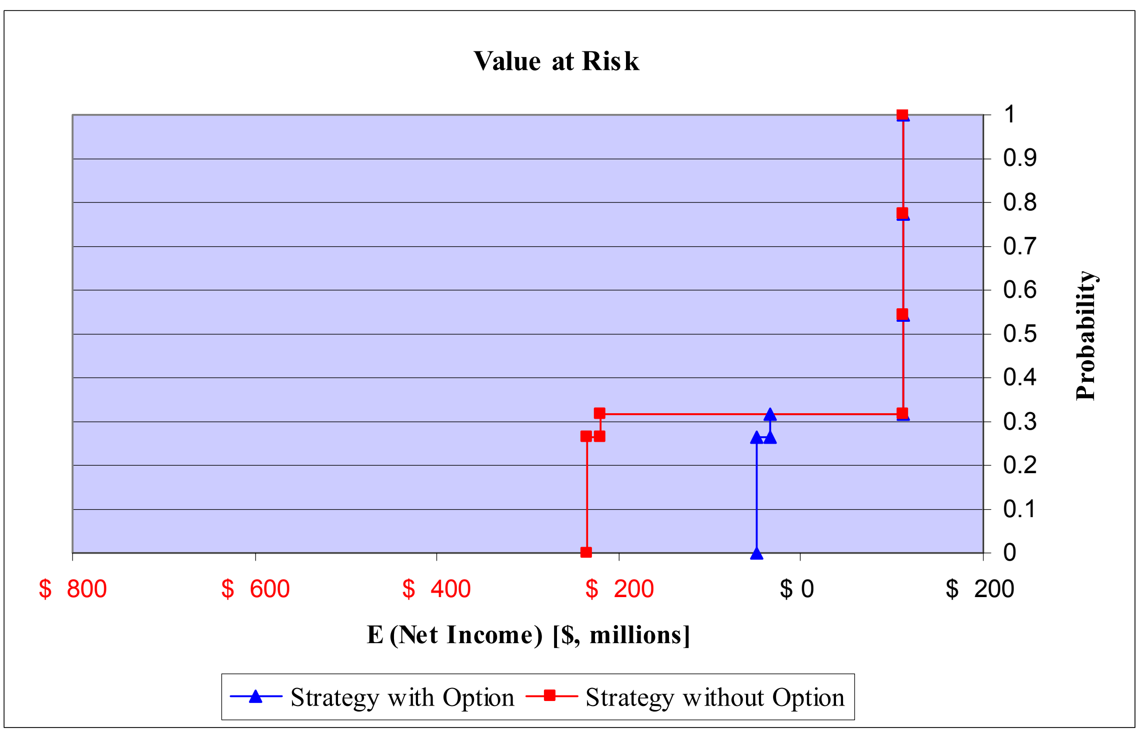


Figure 5-12: New Airport Terminal Model – Multi-functionality can reduce Downside Risk

Ensure Expandability

In addition to deferring decisions outside of the critical path and ensuring multi-functionality, real options thinking also places great value on maintaining the ability to expand. Within the context of airports, landbanking is one popular means of making sure that facilities have room to grow. Again, the New Airport Terminal Model allows for an evaluation of this option within the context of a simplified, hypothetical airport.

Table 5-5: Deferring Decisions Evaluation – Two Strategies

		Planners With Option	Planners Without Option
Period I	**Big NC Strategy**	No LCC Capacity 10 million for NC	No LCC Capacity 10 million for NC
	Big LCC Strategy	10 million for LCC No NC Capacity	10 million for LCC No NC Capacity
Period II	**Expand for LCC**	Either 5 million for LCC or No change	No change
	Expand for NC	Either 5 million for NC or No change	No change

In this scenario, planners again choose to build customer-specific capacity for either 10 million LCC or 10 million NC annual passengers. Whereas one strategy does not allow for expansion after that, a second strategy permits an increase in capacity of 5 million annual passengers for either customer in Year 10. Comparing the two strategies provides for an evaluation of the expansion option.

Table 5-6 shows three cases in which expansion is desired: if planners chose to build for the non-dominant carrier in Period 1 (A1 and B2) or if the probability of revenue growth outstrips the capacity available to the airport (B1). In the first two cases, additional construction corrects for earlier errors; in the third, it allows the airport to take advantage of new growth.

Table 5-6: Ensuring Expandability Evaluation - When to Expand

	A1	A2	B1	B2
E(NPV) [k$]	$254,962	$67,837	$175,204	$101,662
Best Choice	D	E	D	D
Best Choice	Build Big	Build Small	Build Big	Build Big

Within the parameters of this scenario, maintaining the ability to expand increases the upside gains associated with the airport project. However, Figure 5-15 also reveals a reduction in downside losses due to the possibility of corrective expansion.

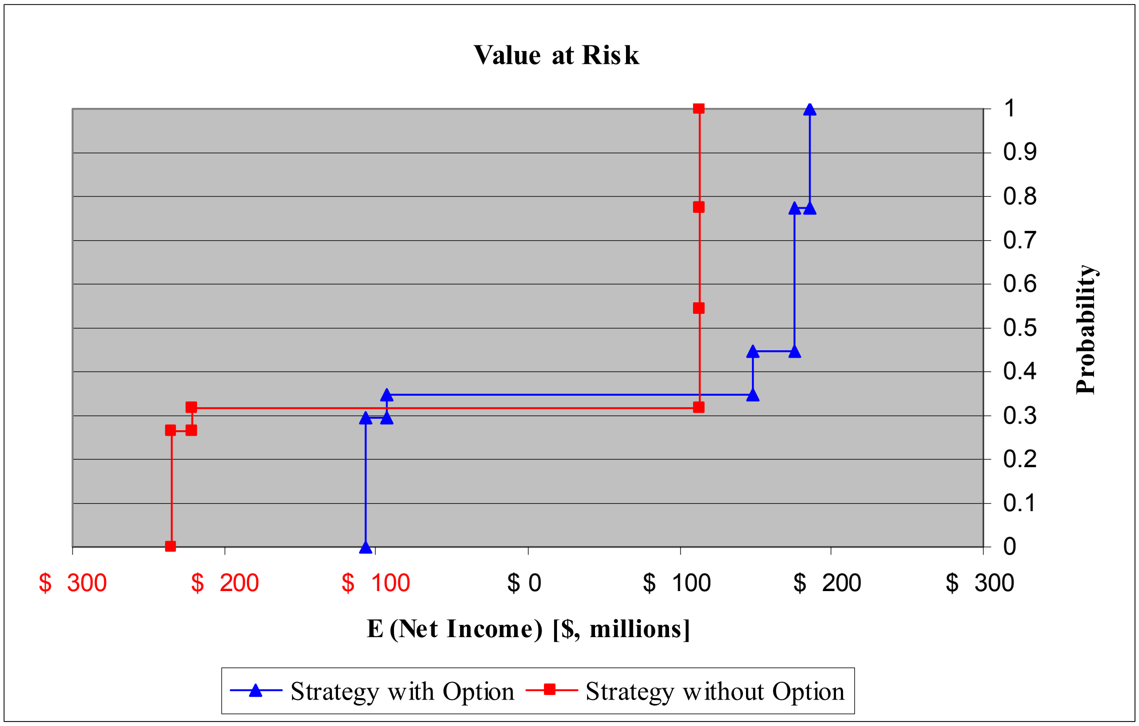


Figure 5-13: New Airport Terminal Model – Expandability shifts the VaRG curve

5. The New Airport Terminal Model: Lisbon Airport Scenario

Having considered the benefits of real options through a variety of simple scenarios using the New Airport Terminal Model, it is now possible to evaluate a much more complicated set of decisions. Whereas the previous scenarios only considered the value of one real option at a time, such a simplified analysis is not well suited to considering the breadth of options available when creating a new airport. Rather, several alternatives – and the real options they encompass – must be accounted for at the same time. The hypothetical Lisbon Airport Scenario considers a more complicated example.

System Development: Period I

Several uncertainties may affect the design of a successful terminal structure at the New Lisbon International Airport (here referred to as NLA). These include the availability of external funding from the European Union, the lifetime of Portela Airport (LIS) after NLA opens, the trends governing low-cost and network carriers in the airport region, and the overall strength of the air transportation industry in Portugal. Modeling each of these possibilities in a decision tree would quickly yield a "messy bush" wherein the number of individual nodes grows exponentially with each new building alternative or chance outcome. Therefore, the configuration of the New Airport Terminal Model presented below focuses first on the development of LCC in Period I and on the total air transportation industry in Period II.

Main Uncertainty: Who will provide the majority of NLA traffic?

Period I examines the first ten years after the opening of the New Lisbon International Airport, during which the primary uncertainty is assumed to concern which group – low-cost or traditional network carriers – will provide the majority of service at the airport.

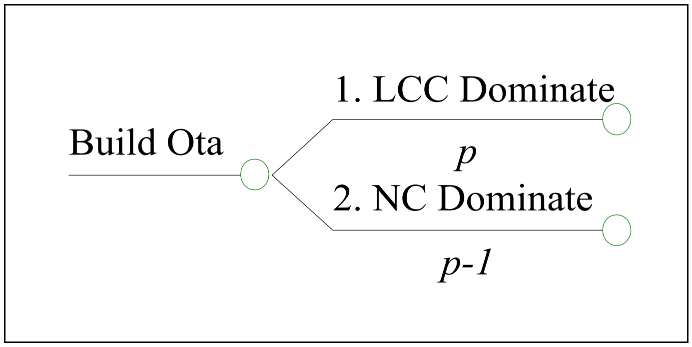


Figure 5-14: Period I Chance Outcomes

Given that NLA is constructed, two possibilities are assumed. The airport will either primarily serve low-cost carriers with probability, p, or network carriers with probability (p-1). The two chance outcomes imply very different revenue streams and cost structures for the airport.

System Development: Period II

Main Uncertainty: How rapidly will NLA's air traffic develop over the next 15 years?

In Period II, which lasts from Year 10 to Year 25 of airport operation, the main cause of concern for airport operators is the development of traffic. This development may depend on several external factors including economic growth in Portugal and the Lisbon region relative to other areas worldwide, trends in fuel prices, the development of competing transportation modes such as road and rail, and the preference for face-to-face rather than internet communication for business transactions. Further, the ability of the Portuguese interests to transfer traffic from Portela to the new airport – a task which has proven difficult in several similar situations worldwide – could also have a significant impact on the long term growth rate at New Lisbon International.

This aggregation of different chance outcomes highlights one strength of decision trees relative to binomial lattice models. Whereas the development of a binomial lattice requires assumptions regarding the growth rate of traffic over the total lifetime of the airport, the decision tree model can accommodate step changes in that growth rate resulting from a series of unpredictable factors.

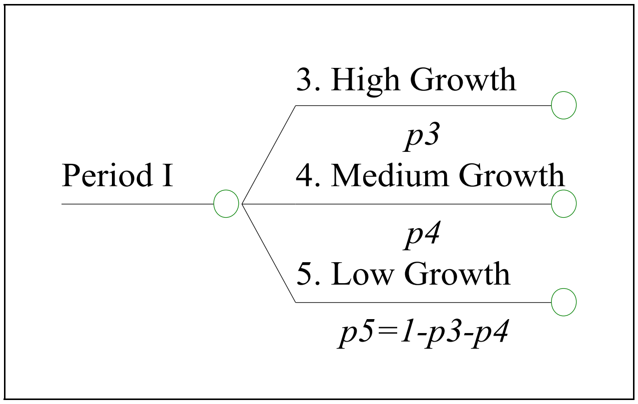


Figure 5-15: Period II Chance Outcomes

For the purposes of the model, the plausible growth rates at the new airport have been aggregated to represent high growth, which occurs with probability *p3*, medium growth (*p4*), and low growth (*p5*), as in Figure 5-17.

Sample Data

The Lisbon Airport Scenario deals with a higher level of complexity than each of the previous real options examinations. This is evident in that it provides room to consider new construction strategies and to incorporate forecasting into the planning process.

A Third Alternative

In the Lisbon Airport Scenario, planners regain the capability to evaluate three rather than two construction alternatives in Period I. Aside from granting planners the ability to consider more alternatives simultaneously, this third option explores the full versatility of the New Airport Terminal Model. Within the context of this scenario, the third alternative allows planners to consider the ramifications of building a much smaller airport initially. Whereas construction alternatives A and B focus on building large facilities for network carriers and low-cost carriers respectively, alternative C allows for the creation of a minimum-capacity facility which does not particularly favor either customer group. Alternative C, therefore, explores two real options principles. First, it calls for a strategy of incremental development. Second, it defers the decision on whether the airport should primarily serve the low-cost or network carrier customer until Period II.

Table 5-7: Lisbon Airport Scenario – Three Strategies

	Construction Strategy	Capacity Built [Mpax]
Period I	A. Big NC	5 million for LCC 5 million for LCC
	B. Big LCC	25 million for LCC 5 million for NC
	C. Build for Both	10 million for LCC 10 million for NC
Period II	Expand if LCC dominant	20 million for LCC No change to NC
	Expand if NC dominant	No change to LCC 20 million for NC
	No Expansion	No change to LCC No change to NC

Path Dependence of Probabilities

Unlike previous iterations of the New Airport Terminal Model, the Lisbon Airport Scenario allows for past decisions to affect future probabilities. In this case, the size of the construction at the start of Period II affects the probabilities describing low, high, and medium growth in Years 10 - 25. This initiative is meant to incorporate known evidence: the experiences of airports like Frankfurt/Hahn (HHN), Baltimore/Washington Thurgood Marshall International (BWI), and Denver/International (DIA) indicate that airlines are attracted to facilities which can accommodate their growth most easily.

Entries Form A

Purpose: Accepts user inputs in white squares as to the probabilities of specific events.

PERIOD I: THE FIRST 10 YEARS

Event		Assumed Probability	Default Value
1 LCC dominant	*P* =	65.00%	65.00%
2 NC dominant	*(1-P)* =	35.00%	35.00%

Discount Rate	0.12

PERIOD II: THE REMAINING 15 YEARS

LCC Dominant

Given Decision: Build Big (D), LCC Dominant (1)

Event		Assumed Probability	Default Value
3 High Growth	*LD3* =	40.00%	35.00%
4 Med. Growth	*LD4* =	60.00%	50.00%
5 Low Growth	*LD5* =	0.00%	15.00%
	Total	100%	100%

Given Decision: Build Small (E), LCC Dominant (1)

Event		Assumed Probability	Default Value
3 High Growth	*LE3* =	20.00%	35.00%
4 Med Growth	*LE4* =	45.00%	50.00%
5 Low Growth	*LE5* =	35.00%	15.00%
	Total	100%	100%

NC Dominant

Given Decision: Build Big (D), NC Dominant (2)

Event		Assumed Probability	Default Value
3 High Growth	*ND3* =	23.00%	15.00%
4 Med. Growth	*ND4* =	57.00%	50.00%
5 Low Growth	*ND5* =	20.00%	35.00%
	Total	100%	100%

Given Decision: Build Small (E), NC Dominant (2)

Event		Assumed Probability	Default Value
3 High Growth	*NE3* =	10.00%	15.00%
4 Med Growth	*NE4* =	45.00%	50.00%
5 Low Growth	*NE5* =	45.00%	35.00%
	Total	100%	100%

Figure 5-16: Lisbon Airport Scenario Path Dependent Probabilistic Growth Rates

Forecasts

In order to correctly size each element of the construction project, the Lisbon Airport Scenario employs forecasts provided within the Terminal Model. Given the input values partially described in Figure 5-18, the forecasts presented in Figure 5-19 are observable. As in the Runway Model, the forecasts closely match those already created for the New Lisbon International Airport: according to the model, probability-adjusted expected value of traffic in 2039 is 33.3 million annual passengers.

		High Growth Forecast [kpax]	Medium Growth Forecast [kpax]	Low Growth Forecast [kpax]
LCC Dominant	LCC component	58,000	39,000	22,000
	NC component	5,000	3,000	3,000
NC Dominant	LCC component	5,000	3,000	3,000
	NC component	31,000	21,000	12,000

Figure 5-17: Lisbon Airport Scenario - 25 Year Traffic Forecasts

Construction of the airport facilities in Period I are designed to closely mirror the medium growth forecast. If the airport planners decide to build under the belief that network carriers will dominate (A), for instance, they build to the forecast: room is allocated for 21 million NC passengers and only 3 million LCC passengers per year. Choosing to construct primarily for the low-cost carrier (B) similarly follows the forecasts for LCC dominance.

Capacities							
Initial Capacities (people)					**Capacity Increases (people)**		
Decision	LCC	NC				LCC	NC
A. Big NC	5,000,000	25,000,000	A	D	Build Big(LCC)	20,000,000	0
B. Big LCC	25,000,000	5,000,000	B	D	Build Big(NC)	0	20,000,000
C. Small Ota	10,000,000	10,000,000	C	E	Build Small (LCC)	0	0
				E	Build Small (NC)	0	0

Figure 5-18: Lisbon Airport Scenario – Terminal Capacities

Capacity additions in Period II, meanwhile, are meant to complement decisions made in Period I. Choices (D), for example, are sized such that they augment construction strategies from Period I. For instance, if planners choose to build the smaller option (C) in Period I, Period II will allow them to expand the airport in order to capture the benefits of passenger growth. Decisions in Period II also allow the flexibility to correct planning errors in Period I. For instance, if the new airport is designed to suit the dominance of the network carrier but LCC prove more important, planners can construct a large LCC-suited structure in order to compensate. Finally, construction decisions in Period II allow for the airport to compensate if passenger volumes are higher than expected or to remain at the current capacity (E). However, as at real airports, it is not possible to reduce capacity; wasted construction cannot be recovered. It should be noted that the maximum capacity of the theoretical airport is 50 million annual passengers, 10 million more than at NLA.

Lisbon Airport Scenario Results

Results after Period 1

As the Lisbon Airport Scenario is significantly more complex than its predecessors, it becomes useful to analyze the results of each decision at the end of both Period I and Period II. As depicted in Figure 5-21, Alternative (C) provides the best results, showing a net loss of US \$599 million in present dollars. Alternatives (A) and (C) yield net losses of US \$1.2 billion and US \$839 million respectively, in present dollars.[15]

Results | Period I only			
	Build Big for NC (A)	Build Big for LCC (B)	Build Small for Both (C)
E(NPV) [k\$]	\$1,182,466	\$839,937	\$598,361

Figure 5-19: Lisbon Airport Scenario - Period I Results

[15] It should be noted that the negative NPV values reflect that the hypothetical airport considered in the Lisbon Airport Scenario has not yet managed to repay the costs of investment within the time period under examination. This is not unusual for airports of a significant size, as is discussed in the later sections.

Results after Period II

The results after Period II can be examined in two stages. Considering expected returns independently of which carrier type dominates is particularly informative. Figure 5-22 reveals that, if airport planners successfully forecasted which carrier type would become dominant in Period I (cases A2 and B1), no new construction is required. For instance, if designers constructed the terminal building to NC parameters and network carriers indeed dominate the market (A2), they need not continue construction (E / Build Small) in Period II. However, large construction projects may be required if planners incorrectly choose which carrier type will lead the market (A1).

Outcome Specific Results | 2 Periods

	A1	A2	B1	B2
E(NPV) [k$]	$734,163	$784,527	$268,812	$625,448
Best Choice	D	E	E	E
Best Choice	Build Big	Build Small	Build Small	Build Small

	C1	C2
E(NPV) [k$]	$224,021	$262,051
Best Choice	E	E
Best Choice	Build Small	Build Small

Figure 5-20: Lisbon Airport Scenario - Partial Results

Overall Results | 2 Periods

	A		B
E(NPV) [k$]	$751,791		$393,635
Gain in P2	*$430,675*		*$446,303*

	C
E(NPV) [k$]	$237,331
Gain in P2	*$361,030*

Best Choice

In Period I, the best choice is to		**Build for Both (C)**
E (NPV)	$237,331	[k$]

Figure 5-21: Lisbon Airport Scenario - Final Result

Considering the probabilities associated with LCC or NC dominance gives the result that airport planners should choose to build a small, hybrid LCC/NC facility in Period I, as shown in Figure 5-23. Looking back to Figure 5-22, the best outcome after building a smaller facility in Period I is to build another small facility in Period II. This result is counterintuitive, as the capacity provided by this path is significantly less than predicted by the medium growth forecast. The result is also not particularly well aligned with the low growth forecast. An analysis of this result follows.

Lisbon Airport Scenario Analysis

The results of the theoretical Lisbon Airport Scenario provide interesting data regarding not only real options but also about the common logic of building airports to suit the forecast capacity. The following subsections discuss these issues in detail.

Deferring Decisions

The above analysis makes one point most clearly. Forecasting the type of customer served and unilaterally choosing to cater to that customer can prove costly. Figure 5-24 illustrates the difficulties associated with incorrect forecasting within the context of the hypothetical Lisbon Airport Scenario. Detailed analysis of the model's calculations proves this result.

Prediction Costs (no new capacity in Period II)		
Prediction	**Outcome**	**25 Year NPV [$, millions]**
LCC Dom	Predict Right	-269
	Predict Wrong	-635
	Difference	366
NC Dom	Predict Right	-785
	Predict Wrong	-961
	Difference	176

Figure 5-22: Lisbon Airport Scenario - Costs of Predictive Action

In order to analyze this phenomenon, it is necessary to compare the effects of predicting traffic types in Period I without considering the airport planner's ability to construct a second terminal at Year 15. This temporary assumption removes the planner's ability to correct erroneous conclusions reached in Period I. In effect, if the airport is built for LCC carriers, this section of the analysis precludes constructing capacity for network carriers in Period II. The assumption will be nullified later.

Under the conditions described above, poor predictions can prove quite costly. If airport planners assume incorrectly that network carriers will dominate airport traffic and build to that assumption, a penalty of US $176 million is incurred. Incorrectly assuming that LCC will dominate, however, leads to a higher penalty of US $366 million.

Correction Costs				
Prediction	Outcome	New Capacity Required [Mpax]	Construction Cost/Yr [$, millions]	NPV (Construction) [$, millions]
LCC Dom	Predict Right	0	n/a	n/a
	Predict Wrong	20 (for NC)	107	234
NC Dom	Predict Right	0	n/a	n/a
	Predict Wrong	20 (for LCC)	71	156

Figure 5-23: Lisbon Airport Scenario - Costs of Corrective Action

Rescinding the assumption that airport planners cannot correct for past errors does not significantly change the picture. For instance, ameliorating a situation in which the first terminal was constructed for NC capacity that did not appear requires constructing capacity for 20 million annual passengers (as per the inputs in Figure 5-20) for low-cost carriers at Year 15. This results in a loss of US $71 million for fifteen years (a total of US $156 million in Year 1 dollars) in order to pay for the construction effort. This correction would reduce the losses incurred from a poor prediction from US $961 million to $734 million.

If, however, airport planners incorrectly assumed LCC dominance, the costs of correcting the error are significantly greater. Constructing a second terminal with the capacity for 20 million annual NC customers would require US $107 million for 15 years, or a total of US $234 million in Year 1 dollars. In this case, the costs of correction are so high that they could not be recovered within the time period analyzed by the New Airport Terminal Model. As a result, the model shows that the benefits of correcting the error simply do not necessitate the costs. Rather, Figure 5-22 illustrates that – if the airport only remains open for 25 years – it is better to do nothing at all (E/ Build Small) in this case (B2).

Incremental Development

The New Airport Terminal Model's second major finding lies in its support of the incremental development concept. According to the results of the hypothetical Lisbon Airport Scenario, constructing smaller terminals is widely preferred to building larger ones.

First, the model suggests that constructing a smaller hybrid terminal in Period I produces superior financial results than constructing a larger terminal to primarily serve either the LCC or NC customer. Second, the model concludes that choosing not to increase capacity in Period II is almost always the superior alternative. Indeed, it only suggests building new capacity in one case where a false prediction requires corrective action. Figure 5-26 reproduces this result. Secondary cases presented in the appendices bolster this conclusion and further explore the concepts of hybridization and switching within the context of the hypothetical Lisbon Airport Scenario.

Lisbon Airport Scenario Construction Strategies				
Building Plan	Overall Ranking	Outcome	Period II: Build New Capacity?	NPV [$, millions]
Build for Both	First	LCC Dominant	No	-237
		NC Dominant	No	
Big LCC	Second	LCC Dominant	No	-394
		NC Dominant	No	
Big NC	Third	LCC Dominant	Yes	-752
		NC Dominant	No	

Figure 5-24: Lisbon Airport Scenario - Comparing Strategies

Two Important Considerations

In drawing conclusions from the Lisbon Airport Scenario, two important considerations are due further thought. First, the current parameters of the New Airport Terminal Model restrict it to the analysis of only twenty-five years of airport operation. Many airports would be incapable of recovering all costs within this period. Frankfurt/Hahn, despite having experienced exceptional growth, expects to see its first annual surplus in 2009, some 16 years after opening to civil aviation (Frankfurt/Hahn, 2007a)[16]; Japan's Osaka/Kansai is expected to take 30 years to pay off its debt alone (Dempsey, 2000). It is therefore possible that extending the period analyzed by the model will change its results. Figure 5-27 illustrates.

Lisbon Airport Scenario Period II Gains			
Building Plan	Overall NPV Ranking	E(Period II Gain) [NPV, $ million]	Period II Gain Ranking
Build for Both	First	361	Third
Big LCC	Second	446	First
Big NC	Third	431	Second

Figure 5-25: Lisbon Airport Scenario - Period II Gains

Although building a smaller terminal in Period I – and not increasing its size thereafter – produces the best financial results over a twenty-five year period, the net income provided by such a construction plan during the last fifteen years of airport operation (Period II) is rather small when compared to other alternatives. As a result, although the "Build for Both" strategy may break-even most rapidly, it does not necessarily produce the highest profit levels over longer periods of time. Conversely, the "Big LCC" alternative produces the greatest net income in Period II; this result is discussed further on.

---

[16] For reference, all outcomes within the hypothetical Lisbon Airport Scenario yield positive annual earnings before interest, taxes, depreciation and amortization (EBITDA) within ten or eleven years after opening. Frankfurt/Hahn achieved this goal in 2007, 14 years after its opening.

This realization explains the counterintuitive result that the airport, if constructed according to the "Build for Both" strategy, ought not to be expanded during Period II. According to the model parameters, it is simply impossible for the additional construction to pay for itself before the end of the analysis period. This fact neither negates the conclusions of the New Airport Model nor does it mar the positive conclusions regarding incrementalism, however. Indeed, from the perspective of the airport's financial portfolio, incremental development remains the broadly preferable option. Certainly, increasing the time period investigated does not reduce the risks associated with building large airports before demand necessitates the capacity provided for. Montréal/Mirabel failed to recover its costs in 32 years. Rather, incrementalism still severely reduces the downside risks associated with airport construction, as evidenced by Figure 5-28.

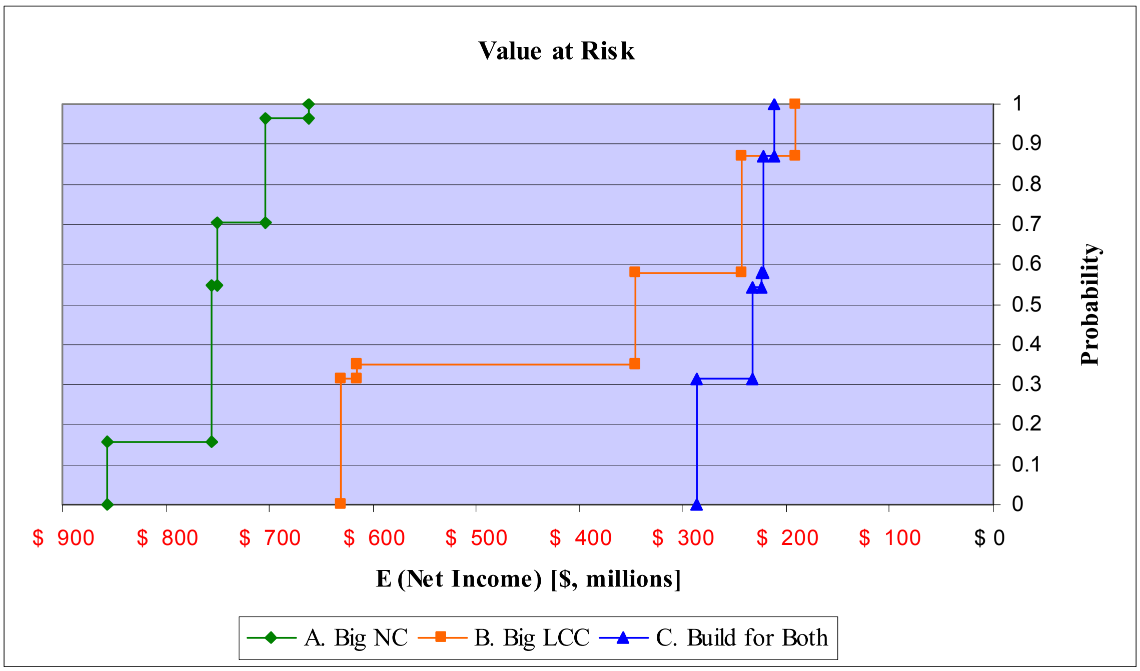


Figure 5-26: Lisbon Airport Scenario - VaRG

A second important consideration is required. The parameters of the New Airport Terminal Model restrict it to considering only the financial portfolio of the given airport. Financial benefits which accrue to the airport region as a result of air traffic – tourism, business, jobs, etc – are not accounted for and are simply beyond the constraints of this thesis. Considering these effects, however, could support the different construction strategies. Nonetheless, the principle of incrementalism remains; constructing capacity before demand necessitates it remains risky.

6. The New Airport Terminal Model: Regional Development Scenario

Given the rise of low-cost carriers and their apparent predilection for secondary airports, some researchers have considered the ability of an LCC-airport archetype as a model for regional development (Hörsch, 2003). Given the stated goals of the Portuguese development regarding increased connectivity between remote regions and the economic development of depressed areas (Portugal, 2005), the idea seems worthy of a hypothetical exploration through the New Airport Terminal Model. The findings of the theoretical Lisbon Airport Scenario, in addition to its support for real options principles, seem to support this examination. In fact, several parameters indicate that choosing to cater to the low-cost carrier may prove broadly preferable for regional development purposes. First, the "Big LCC" construction alternative has the largest upside potential of the three strategies. Second, it provides for the fastest rate of growth in Period II net income, implying significant expected long term benefits of a LCC-favoring strategy. Third, the negative result of incorrectly predicting LCC dominance (US $625 million) is far less than that associated with incorrectly predicting NC dominance (US $961 million), even without accounting for the costs of corrective action.

Certainly, this result is a function of assumptions internal to the input data. The Lisbon Airport Scenario assumes that LCC are more likely to dominate the European passenger market than their NC competitors (Mercer, 2002). Further, the inputs allow LCC to benefit from higher growth rates (Dennis, 2004) and require fewer funds to serve LCC customers (Pitt, 2001).

Nonetheless, recognizing the analytical basis supporting these assumptions reveals an interesting construction path not directly considered by the Lisbon Airport Scenario but relevant to regional development: build for LCC first. Chapter 4 indicates the reasoning presented by Bonnefoy and Hansman: low-cost airports, though generally cheaper to build and maintain than their NC counterparts, not only grow rapidly but also tend to attract larger airlines as they grow (Bonnefoy and Hansman, 2004). The Regional Development Scenario, therefore, explores this possibility. Although all of the population inputs in this scenario are the same as in the Lisbon Airport Scenario, the construction strategies differ. Appendix A6 shows the scenario set-up. The results are presented here in brief.

<u>Regional Development Scenario: System Development & Results</u>

Table 5-8: Regional Development Scenario – Three Strategies for LCC-based Construction

	Construction Strategy	Capacity Built [Mpax]
Period I	**Big LCC Strategy**	25 million for LCC 5 million for NC
	Medium LCC Strategy	10 million for LCC 5 million for NC
	Build for Both Strategy	10 million for LCC 10 million for NC
Period II	**Expand if LCC dominant**	20 million for LCC No change to NC
	Expand if NC dominant	No change to LCC 20 million for NC
	No Expansion	No change to LCC No change to NC

Rather than building primarily for LCC or for NC, the Regional Development Scenario compares the "Big LCC" and "Build for Both" strategies already developed with a plan calling for building a medium-sized LCC facility (Medium LCC). This structure accounts for the benefits of incrementalism while still attempting to cater to the LCC customer. Figure 5-29 presents the results: constructing a medium-sized LCC-serving facility shifts the VaRG curve significantly, both increasing upside gain and downside losses.

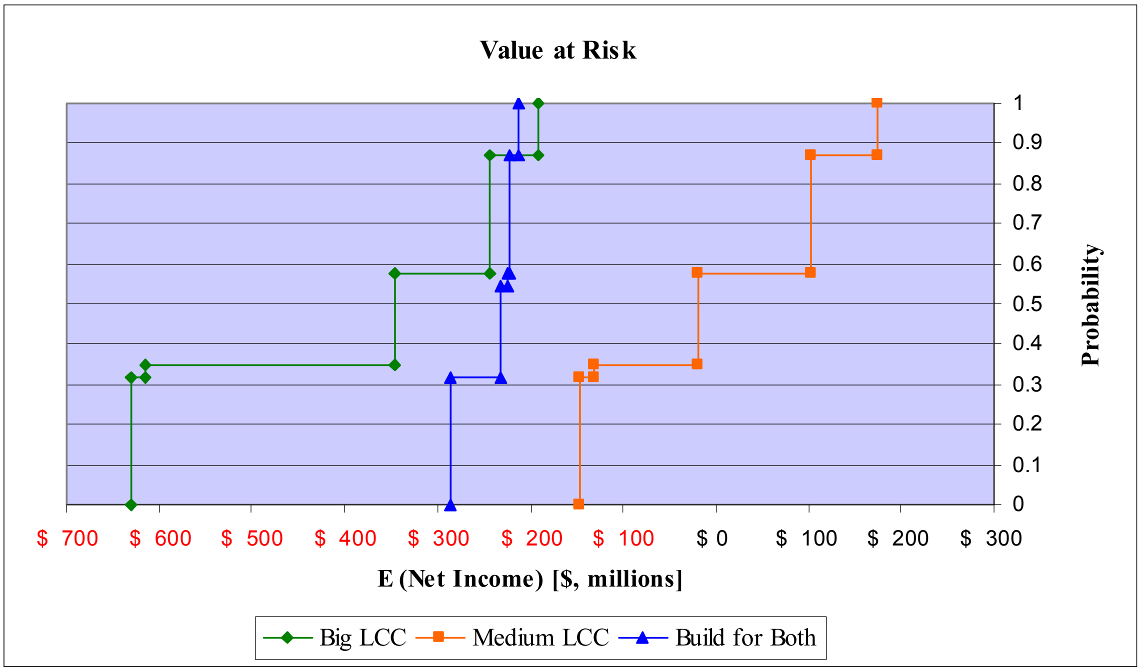


Figure 5-27: Regional Development Scenario - VaRG of LCC-based Strategies

The resulting risk reduction translates into significant differences in overall profit. Granting planners the ability to employ multifunctional facilities and to switch capacity between customer types increases the benefits even further. The following figures show the results of a scenario in which that the capacity for 5 million annual passengers may be switched between customer types at the beginning of Period II.

Table 5-9: Regional Development Scenario – Three Strategies for LCC-based Construction Given Multi-functionality

	Construction Strategy	Capacity Built [Mpax]
Period I	Big LCC Strategy	25 million for LCC 5 million for NC
	Medium LCC Strategy	10 million for LCC 5 million for NC
	Build for Both Strategy	10 million for LCC 10 million for NC
Period II	Expand if LCC dominant	20 million for LCC No change to NC
	Expand if NC dominant	No change to LCC 20 million for NC
	Switch Capacity	5 million to LCC or 5 million to NC

With switching allowed, the argument for a "Medium LCC" construction strategy becomes even more persuasive. Indeed, the use of multi-functional facilities – as defined in the experimental Lisbon Airport Scenario – shifts all the associated value-at-risk/gain curves. Regardless of strategy, downside losses are reduced significantly for the twenty-five year period.

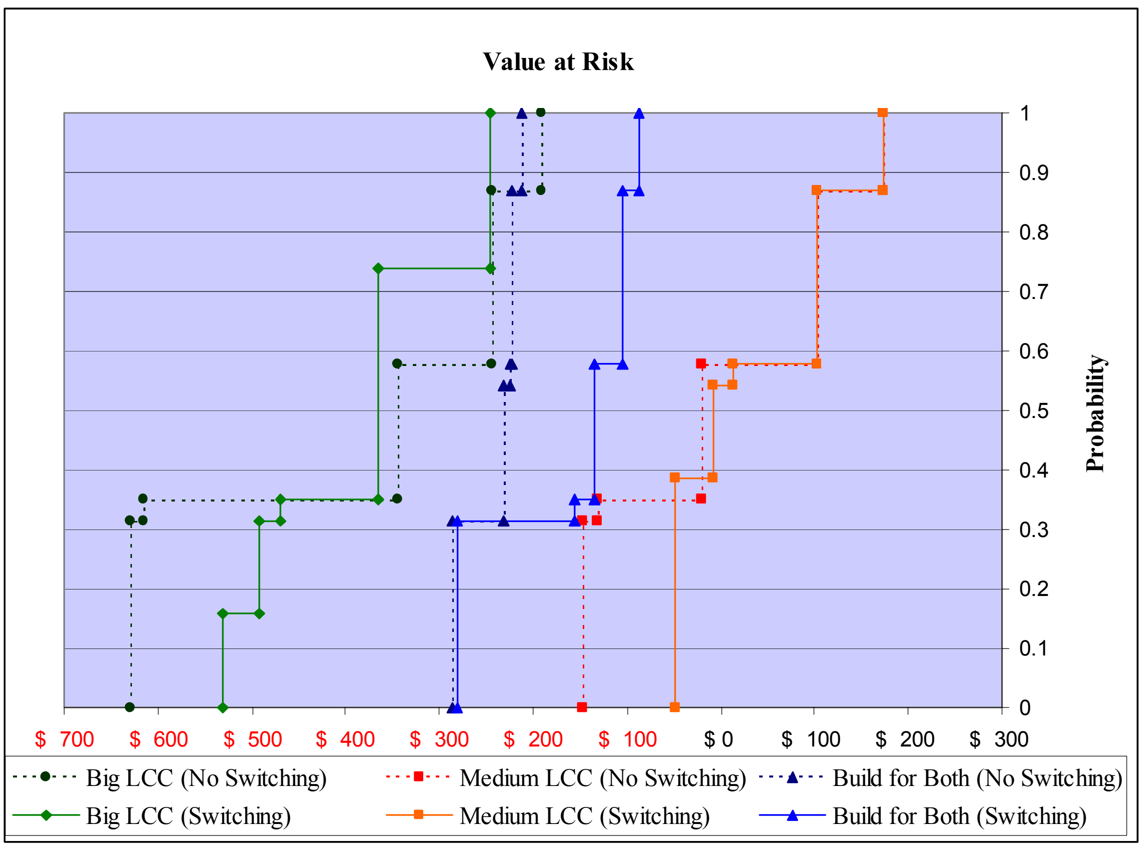


Figure 5-28: Regional Development Scenario – Multi-functionality improves VaRG of LCC-based Strategies

Regional Development Scenario: Analysis

The construction of airports for regional development carries different objectives and risks than airport projects in well-established areas. Surely, the availability of demand is more uncertain. Further, underdeveloped regions may be less likely to attract the operations of network carriers, meaning that the construction of large NC-centered facilities in underdeveloped regions is quite risky. There is a possibility, however, that the growth of LCC may be altering the picture. The Regional Development Scenario highlights some benefits of the approach.

As is well-proven, building a large facility can lead to immense losses. In the hypothetical Regional Development Scenario, an incorrect forecast can lead to losses as great as US $625 million in Year 1 dollars. A new conclusion, however, shows that building a medium-sized LCC facility (Medium LCC alternative) can provide benefits far superior to those provided by constructing a small facility split between LCC and NC use (Build for Both alternative). This result corresponds with the works of Tretheway and Hörsch, who argue that LCC development can provide opportunities for increased airport revenues (Tretheway, undated) and perhaps act as a tool for regional growth (Hörsch, 2003).

LCC-based Strategies				
Strategy	**NPV Ranking**	**Outcome**	**Action**	**25 Year NPV [$, millions]**
Medium LCC	First	LCC Dominant	Build Big for LCC	131
		NC Dominant	Switch	-142
Build for Both	Second	LCC Dominant	Switch	-224
		NC Dominant	Switch	-262
Big LCC	Third	LCC Dominant	No change	-269
		NC Dominant	Switch	-625

Figure 5-29: Regional Development Scenario – Comparing LCC-based Strategies

Given this strategy, the arrival of an LCC at the regional airport provides a US $130 million dollar profit in Year 1 dollars. If NC rather than LCC arrive, however, the right to switch mitigates the associated risk. Hypothetical losses fall from some US $262 million to US $24 million in Year 1 dollars, giving the multi-functionality option an expected value of US $238 million.

LCC-based Strategies with Capacity Switching				
Strategy	**NPV Ranking**	**Outcome**	**Action**	**25 Year NPV [$, millions]**
Medium LCC	First	LCC Dominant	Build Big for LCC	130
		NC Dominant	Switch	-24
Build for Both	Second	LCC Dominant	Switch	-112
		NC Dominant	Switch	-232
Big LCC	Third	LCC Dominant	No change	-269
		NC Dominant	Switch	-507

Figure 5-30: Regional Development Scenario - Results of LCC-based Construction Strategies with Multi-functionality

The implication is simple: given the possibility of low-cost service, a new paradigm for air transport in underserved areas may be developing. Under this structure, stakeholders can choose to build smaller LCC facilities at relatively low cost. As a result, the cost of failure is small compared to the construction of large LCC or NC facilities. Further, the cost of proving unable to attract significant LCC patronage can be mitigated through provisions for multi-functionality. The benefits of success, however, are also great, as evidenced by Liverpool's John Lennon Airport (LPL), Belgium's Charleroi (CRL), and Frankfurt's Hahn (HHN). Attracting a low-cost carrier to the airport not only serves the region well but also allows for the airport to recoup its costs rather rapidly.

7. Peering Backwards: A Review

That uncertainty governs the operation of physical systems is not in question. Rather, several studies – including de Neufville and Odoni, 2003; Flyvbjerg, 2005; Bernanke, 1983 – have proven this within several contexts. Other works emphasize the need for planning methods to mitigate uncertainties and therefore to reduce the risks of extensive loss. What is still required, however, is a demonstration of processes to evaluate the benefits of risk mitigation within the airport context.

This chapter presented two methods for evaluating risk mitigation strategies: the New Airport Runway Model and the New Airport Terminal Model. The first, a scenario reproduction based on binomial lattices, is well equipped to survey issues dealing with the development of a single uncertain parameter, given a historically-determined volatility and growth rate. The latter model, though more complex, allows for replication of more realistic scenarios with changing uncertainties and multiple decision points. Both models, of course, carry respective benefits, drawbacks, and flexibilities. Regardless, both are useful for analyzing decisions within the airport context.

Hypothetical experiments within the New Airport Runway Model, for instance, demonstrate the value which can be offered by the real options concepts of deferring decisions and incremental development. Simplified airport mock-ups within the New Airport Terminal Model, in addition, reveal processes for evaluating the benefits of multi-functionality and expandability as well. In each case, it is clear that – in many cases – the proper use of real options can both reduce the risk of loss and increase the probability of financial gain.

Finally, the more complex Lisbon Airport Scenario and Regional Development Scenario demonstrate methods of comparing a variety of airport development strategies. Although all results are solely dependent on input values, it is nonetheless interesting to note the findings of the hypothetical simulations: real options concepts such as deferring decisions, maintaining expandability, incremental development, and multi-functionality can provide impressive benefits within the airport context. More intriguing, the theoretical scenario suggests that construction strategies focused on building limited facilities catering to low-cost carriers can help offset developing uncertainties within the air transportation industry. Given proper consideration, then, the New Airport Runway Model and the New Airport Terminal Model reveal the usefulness not only of real options thinking but also of the processes for evaluating them.

CHAPTER 6: CONCLUSIONS

Airport planning has always contained an element of uncertainty. Indeed, the construction of most physical systems is subject to unpredictable changes in requirements. Transportation systems, however, appear particularly prone to risk. People usually do not travel for traveling's sake. Rather, the success of a transportation project is closely tied to the demand for tourism and business, to general economic inputs such as regional GDP and income per capita, to oil and gas prices, and to general shifts in customer preferences. Within the context of expensive transportation constructs including high speed rail and aviation, the need for mitigating uncertainty is therefore quite clear.

Although several planning methods have evolved to allow for the proper consideration of uncertainty, many industries still have room for progress. Within air transport, the rigidity of the master planning method has come into question; there has been a call for change. Several major airports have already begun shifting their strategies by steadily abandoning their reliance on pervasively incorrect forecasts (Sydney/Kingsford-Smith) and inflexible master planning (Austin-Bergstrom International). Instead, new facilities have looked to incorporate flexibility (Munich/Franz Josef Strauss) and multi-functionality (Geneva/Cointrin International). In light of these developments, real-options thinking can undoubtedly play a major role in creating new airport planning processes.

Ongoing changes within the airline industry seem to make this shift more important. In an industry where low-cost carriers, multi-airport systems, deregulation, and privatization are steadily reshaping old paradigms, the ability to adapt has become increasingly vital. It is certainly no longer assured that particular airlines will operate regional monopolies and provide airport traffic. Further, it is no longer guaranteed that an airport will garner traffic based on location alone. Rather, in the developing environment, it appears that airline and airport differentiation will increase: many airports will need to adapt to changing customer requirements. Here, real options and its principles of deferring decisions, incrementalism, ensuring expandability, and providing for multi-functionality can prove most useful.

The thesis conclusions bolster this thinking. Example airports and mathematical scenarios, for instance, demonstrate the possible benefits of incremental or phased development. At Dallas/Fort Worth Airport (DFW), for one, planners matched their construction strategies to proven growth rates; Hong Kong International (HKG), alternatively, uses self-propelled people movers to allow managers to quickly support demand increases. The power of deferring decisions outside of the critical path is also made evident; in an environment where customer requirements are changing, deferral can both significantly reduce downside risks and increase the probability of success as at Austin-Bergstrom International Airport (AUS). At the same time, the research demonstrates the considerable advantages which can be accrued through maintaining alternatives for growth through landbanking (as at the UPS WorldPort) or through the upkeep of military airfields, as at Frankfurt/Hahn (HHN). Moreover, the gains available from multi-functionality become evident both through examination of facilities such as Geneva/Cointrin (GVA) and through theoretical analysis. In short, real options planning presents an opportunity both to reduce the risk of loss and to increase the possibility of financial gain within airport systems worldwide.

Nonetheless, two requirements must be fulfilled in order for real options to become the standard approach. First, real options thinking must be adopted by stakeholders throughout the aviation industry. Second, common methods for evaluating option value must gain prominence. In addition to simply showing the benefits of flexible planning under certain conditions, this thesis takes action to further both of these requirements.

By examining the goals and powers of various airport stakeholders, it becomes clear that the validity and usefulness of various flexible solutions differ not only on the basis of the particular airport but also on the basis of the airport actors. Whereas international organizations are well poised to change the language of airport planning, national and regional groups have the power to enforce change and to pursue real options "on" airport systems by promoting landbanking, maintaining development options, and supporting co-modality. Airport owners, planners, and managers, however, are uniquely positioned to apply flexible planning methods to specific engineering decisions by employing modularity and multi-functionality.

Finally, the thesis' two models tackle the promotion of stakeholder-independent means for the preliminary evaluation of options principles. The New Airport Runway Model and the New Airport Terminal Model, therefore, provide for rapid comparison between simple airport construction strategies and can prove useful within pedagogical contexts. More important, the models demonstrate methodologies for analyzing flexibility and highlight the benefits which real options can offer to airport development projects worldwide. Through hypothetical analyses of the New Lisbon International Airport, it therefore becomes clear not only that real options can have positive implication for air transport planning, but also that the proper evaluation of real options strategies can become commonplace.

BIBLIOGRAPHY

[1] Aguado, V. (2006). *A vision for European aviation.* Presented at the Eurocontrol and ACI Europe Press Conference on January 18, 2006 on behalf of Eurocontrol. Retrieved July 27, 2007, from http://www.eurocontrol.int/corporate/public/standard_page/org_dg_speeches_2006.html.

[2] Airport Innovation. (2007). Airport cities & the aerotropolis: New planning models – An interview with Dr. John D. Kasarda. *Airport Innovation, 2007* (April). Retrieved July 23, 2007, from http://www.aerotropolis.com/files/2007_04_AirportInnovation_NewPLanningModels.pdf.

[3] Airport-Technology.com. (2005). *Take off for a low-cost airport*. Retrieved July 7, 2007, from http://www.airport-technology.com/features/feature545/.

[4] Airports Council International (ACI). (2006). *ACI policy handbook: 5th edition*. Geneva: ACI World Headquarters.

[5] Airports Council International (ACI). (2007). *ACI overview: The community of airports*. Retrieved June 20, 2007, from http://www.airports.org/cda/aci_common/display/main/aci_content07_c.jsp?zn=aci&cp=1-2-4622_666_2__.

[6] American Society of Civil Engineers (ASCE). (2001). *US engineering society names Kansai International Airport a civil engineering monument of the millennium*. Retrieved July 17, 2007, from http://www.asce.org/pressroom/news/pr041901_kansai.cfm.

[7] Association of European Airlines (AEA). (2007). *AEA airlines' delay rates by airport on intra-European services*. Retrieved July 24, 2007, from http://www.aea.be/aeawebsite/webRSC/SerQlty/PRP_SS_06.htm.

[8] Austin Bergstrom International Airport (AUS). (2007). *Awards and honors*. Retrieved July 17, 2007, from http://www.ci.austin.tx.us/austinairport/awards.htm.

[9] Australia Department of Aviation & Kinhill Stearns (Australia). (1985). *Second Sydney Airport: Site selection programme: Draft environmental impact statement*. Canberra: Dept. of Aviation.

[10] Australia Department of Aviation & Kinhill Stearns (Australia). (1985a). *Second Sydney Airport site selection programme: Supplement to the draft environmental impact statement: Prepared for the Department of Aviation.* Ultimo, Australia: Kinhill Stearns.

[11] BAA. (2007). *Annual review 2006/07*. Retrieved on August 3, 2007, from http://www.baa.com/annualreview07/our_business_areas/stansted.html.

[12] Babajide, A. (2007). *Real options analysis as a decision tool in oil field developments*. Master's thesis. Massachusetts Institute of Technology, Cambridge, MA.

[13] Barrett, S. D. (2000). Airport competition in the deregulated European aviation market. *Journal of Air Transport Management*, *6* (1), 13 - 27.

[14] Barrett, S. D. (2004). How do the demands for airport services differ between full-service carriers and low cost carriers? *Journal of Air Transport Management, 10* (1), 33 – 39.

[15] Belin, S. C. (2000). *Designing flexibility into airport passenger buildings: the benefits of multifunctional space and facilities*. Master's thesis. Massachusetts Institute of Technology, Cambridge, MA.

[16] Bernanke, B. S. (1983). Irreversibility, uncertainty, and cyclical investment. *The Quarterly Journal of Economics, 98* (1), 85 - 106.

[17] Bonamici, K. (2004). Southwest airlines: The hottest thing in the sky. *Fortune*. Retrieved August 2, 2007, from http://money.cnn.com/magazines/fortune/fortune_archive/2004/03/08/363700/index.htm.

[18] Bonnefoy, P. (2005). *Emergence of secondary airports and dynamics of regional airport systems in the United States.* Master's thesis. Massachusetts Institute of Technology, Cambridge, MA.

[19] Bonnefoy, P., & Hansman, R. (2004). Emergence and Impact of Secondary Airports in the United States. *Proceedings of the 4th AIAA ATIO Forum in Chicago, Illinois.* Retrieved August 7, 2007, from http://hdl.handle.net/1721.1/34958 (MIT D-Space database).

[20] British-Portuguese Chamber of Commerce (BPCC). (2007). *Sectorial Reports*. Retrieved August 7, 2007, from http://www.bpcc.pt/airports.asp#ancora2.

[21] Bruns, A. (2006). Overnight Success. *Site Selection Online, 2006* (September). Retrieved July 17, 2007 from http://www.siteselection.com/features/2006/sep/logistics/index.htm.

[22] Canadian Press (2006, February 21). Mirabel Airport to be turned into amusement park. Retrieved June 11, 2007, from http://www.ctv.ca/servlet/ArticleNews/story/CTVNews/20060221/mirabel_park_060221?s_name=&no_ads=.

[23] Cardiff International Airport (CWL). (2007). *Charges and conditions of use 2007.* Retrieved August 1, 2007, from http://www.cwlfly.com/en/content.asp?area=4&id=242.

[24] Carney, M., & Mew, K. (2003). Airport governance reform: a strategic management perspective. *Journal of Air Transport Management, 9* (4), 221-232.

[25] Caves, R. E., & Gosling, R. (1999). *Strategic airport planning*. New York: Pergamon.

[26] Chevalier, J. (2005). *Portela limitation and the need for a single new airport for Lisbon*. Presented at the Lisbon 2017 Conference in Portugal on November, 22, 2005 on behalf of Aèroports de Paris. Retrieved January 18, 2007, from http://www.naer.pt/portal/page/portal/NAER/Eventos/?CTEV=16661&actualmenu=18859&cboui=16661.

[27] Clark, J., Field, F., & de Neufville, R. (1996). *Manual of case studies and application in dynamic strategic planning, revised version.* Technology and Policy Program. Cambridge, MA: Massachusetts Institute of Technology.

[28] Cohas, F. (1993). *Market-share model for a multi-airport system*. Master's thesis. Massachusetts Institute of Technology, Cambridge, MA.

[29] Cox, J., Ross, S., Rubinstein, M. (1979). Option pricing: A simplified approach. *Journal of Financial Economics, 7* (3), 229 - 263.

[30] Coy, P. (1999). Exploiting uncertainty: The "real-options" revolution in decision-making. *BusinessWeek Online (June 7, 1999)*. Retrieved August 3, 2007 from http://www.businessweek.com/1999/99_23/b3632141.htm.

[31] Crites, J. M., & Bauman, L. (1998). Aviation planning for the 21st Century: DFW International Airport. In M. McNerney (Ed.), *Airport facilities: Innovations for the next century (Proceedings of the 25th International Air Transportation Conference, 1998)*. Reston, VA: ASCE.

[32] Dallas/Fort Worth International Airport (1997). *1997 Airport development plan update: Executive summary*. Retrieved July 14, 2007 from http://www.dfwairport.com/cdp/masterplan.html.

[33] Dallas/Fort Worth International Airport (2006). *DFW Airport 2006 annual report*. Retrieved July 14, 2007 from http://www.dfwairport.com/airport/flash/financial/ar2006/START.html.

[34] de Neufville, R. (1984). Multi-airport systems - How do they work best? *Airport Forum, 1984* (June), 55 - 59.

[35] de Neufville, R. (1986). *Multi-airport systems in metropolitan regions: A guide for policy* (FAA Report, March 1986, NTIS).

[36] de Neufville, R. (1990). Successful siting of airports: The Sydney example. *ASCE Journal of Transportation Engineering, 116* (2), 37 - 48.

[37] de Neufville, R. (1990a). *Applied systems analysis: Engineering planning and technology management*. New York: McGraw-Hill.

[38] de Neufville, R. (1991). Strategic Planning for Airport Capacity: An appreciation of Australia's process for Sydney. *Australian Planner, 29* (4), 174 - 180. Retrieved on July 27, 2007, from http://cee.mit.edu/index.pl?id=10897&isa=Category&op=show.

[39] de Neufville, R. (1991a). Foreword. In Massachusetts Port Authority, *Passenger forecasts of Logan International Airport* (pp. 1 – 13). Boston: Massachusetts Port Authority. Retrieved July 21, 2007, from http://ardent.mit.edu/airports/ASP_papers/understanding%20and%20using%20forecasts.PDF.

[40] de Neufville, R. (1995). Management of multi-airport systems: A development strategy. *Journal of Air Transport Management, 2* (2), 99-110. Retrieved January 2, 2007, from Elsevier ScienceDirect database.

[41] de Neufville, R. (1995a). Designing airport passenger buildings for the 21st century. *Transport Journal, UK Institution of Civil Engineers*, *111*, 83 - 96. Retrieved on July 27, 2007, from http://cee.mit.edu/index.pl?id=10897&isa=Category&op=show.

[42] de Neufville, R. (1995b). *Policy guidelines for the option of a development of a multi-airport system, the basis of a dynamic strategic plan to provide the capability for flexible response to future challenges* (Report prepared for Amsterdam Airport, Schiphol, Netherlands, 1995). Retrieved August 6, 2007 from http://cee.mit.edu/index.pl?id=10897&isa=Category&op=show.

[43] de Neufville, R. (1996). Optimal configuration of complexes of large airport passenger buildings and their internal transport systems. In Académie Nationale de l'air et de l'espace (Ed.), *Airports of the future (Proceedings of the Airports of the Future International Symposium, 1995)* (pp. 342 – 352). Toulouse: Cépadués éditions. Retrieved on July 27, 2007, from http://cee.mit.edu/index.pl?id=10897&isa=Category&op=show.

[44] de Neufville, R. (2000). *Planning multi-airport systems in metropolitan regions in the 1990s* (Prepared for the US Federal Aviation Administration Procurement Order DTFA01-92-P-01243). Retrieved January 7, 2007, from http://ardent.mit.edu/airports/ASP_papers/planning%20for%20multi-airport%20systems.pdf.

[45] de Neufville, R. (2002). Multi-airport systems in the era of no-frills airlines. Washington, DC: Transportation Research Board. Retrieved January 2, 2007, from http://ardent.mit.edu/airports/ASP_papers/no-frillstrbtext.pdf.

[46] de Neufville, R. (2005). The future of secondary airports: nodes in a parallel air transport network? *Cahiers Scientifiques du Transport, 2005* (24), 11- 38. Retrieved January 2, 2007, from http://ardent.mit.edu/airports/de_Neufville_airport_papers.html

[47] de Neufville, R. (2006). Planning airport access in an era of low-cost Airlines. *Journal of the American Planning Association, 72* (3), 337-346. Retrieved on July 27, 2007, from http://cee.mit.edu/index.pl?id=10897&isa=Category&op=show.

[48] de Neufville, R., & Odoni, A. (2003). *Airport systems planning, design, and management*. New York: McGraw-Hill.

[49] de Neufville, R., & Neely, J. (2001). Hybrid real options valuation of risky product development projects. *International Journal of Technology, Policy and Management, 1* (1), 29 - 46. Retrieved on July 27, 2007, from http://cee.mit.edu/index.pl?id=10897&isa=Category&op=show.

[50] de Neufville, R., Scholtes, S., Wang, T. (2006). Valuing Options by Spreadsheet: Parking Garage Case Example. *ASCE Journal of Infrastructure Systems, 12* (2), 107-111. Retrieved on July 27, 2007, from http://cee.mit.edu/index.pl?id=10897&isa=Category&op=show.

[51] de Weck, O., de Neufville, R., & Chaize, M. (2004). Staged development of communication satellite constellations in low orbit. *Journal of Aerospace Computing, Information, and Communication, 1* (3), 119-131. Retrieved on July 27, 2007, from http://ardent.mit.edu/real_options/Common_course_materials/papers.html.

[52] Dempsey, P. S. (2000). *Airport planning and development handbook: A global survey*. New York: McGraw-Hill.

[53] Dempsey, P. S., Goetz, A. R., & Szyliowicz, J. S. (1997). *Denver International Airport: Lessons learned*. New York: McGraw-Hill.

[54] Dennis, N. (2004). Can the European low cost airline boom continue? Implications for regional airports: *The 44th European Congress of Regional Science Association.* Porto, Portugal. Retrieved online on January 4, 2007, from http://ideas.repec.org/p/wiw/wiwrsa/ersa04p571.html.

[55] Department for Transport (DfT). (n.d.) *Guidance on the preparation of airport master plans*. Retrieved August 2, 2007, from http://www.dft.gov.uk/about/strategy/whitepapers/air/pwpa/guidanceonthepreparationofai5682.

[56] Doganis, R. (2006). *The airline business, 2nd edition*. London: Routledge.

[57] easyJet airline company (2006). *Routemap*. Retrieved July 24, 2007, from http://www.easyjet.com/EN/Planning/Destination/.

[58] Economist Intelligence Unit (Economist). (2007). *Portugal: Travel and tourism profile*. Retrieved March 27, 2007, from http://www.eiu.com/index.asp?layout=IWArticleVW3&article_id=861964471&refm=iwIndustryProfile&industry_id=320000032&country_id=&page_title=Profiles>.

[59] Etzioni, A. (1967). Mixed-scanning: A third approach to decision making. *Public Administration Review, 27*, 385 - 392.

[60] European Organization for the Safety of Air Navigation (Eurocontrol). (2006). *Low-cost carrier update: May 2006* (Eurocontrol/Statfor Doc195 v1.0). Eurocontrol. Retrieved online on July 24, 2007, from http://www.aea.be/aeawebsite/webrsc/resources/LowCostMarketUpdateMay06.pdf.

[61] European Union Commission of the European Communities (EU). (2001). *European Transport Policy for 2010: Time to Decide*. Luxembourg: Office for Official Publications of the European Communities. Retrieved July 17, 2007, from http://ec.europa.eu/transport/white_paper/documents/doc/lb_texte_complet_en.pdf.

[62] European Union Commission of the European Communities (EU). (2005). *Community Guidelines on Financing of Airports and Start-Up Aid to Airlines Departing from Regional Airports*. Brussels: Commission of the European communities. Retrieved July 17, 2007, from http://ec.europa.eu/transport/air_portal/consultation/2005_03_07_en.htm.

[63] European Union Commission of the European Communities (EU). (2006). *Proposal for a regulation of the European Parliament and the Council on common rules for the operation of air transport in the Community (recast)* (2006/0130). Brussels: Commission of the European Communities. Retrieved July 17, 2007, from http://eur-lex.europa.eu/LexUriServ/site/en/com/2006/com2006_0396en01.pdf.

[64] European Union Commission of the European Communities (EU). (2007). *An action plan for airport capacity, efficiency, and safety in Europe* (SEC (2006) 1686 and SEC (2006) 1687). Brussels: Commission of the European Communities. Retrieved June 21, 2007, from http://ec.europea.eu/transport/air_portal/airports/doc/2007_capacity_en.pdf.

[65] Farmer, P. (2002). Airspace: The flexible terminal solution for sustainable 'low cost' airline growth. *Airport International, 2002*. Retrieved July 18, 2007 from http://www.airport-int.com/categories/modular-terminal-solutions/airspace-flexible-terminal-solution-for-sustainable-low-cost-airline-growth.asp.

[66] FitchRatings.com (2006). Denver International Airport. Retrieved July 17, 2007 from http://www.flydenver.com/diabiz/stats/financials/reports/fitch_july2006.pdf.

[67] Flyport (2007). *Flyport: the modular passenger terminal*. Retrieved July 18, 2007 from http://www.flyport.info/en/index.html.

[68] Flyvbjerg, B., Holm, S., & Buhl, S. (2002). Underestimating costs in public works projects: Error or lie? *Journal of the American Planning Association*, *68* (3). Retrieved January 2, 2007 from ABI/INFORM Global.

[69] Flyvbjerg, B., & Holm, S (2005). How in(accurate) are demand forecasts in public work projects? The case of transportation. *Journal of the American Planning Association*, *71* (2). Retrieved January 2, 2007 from ABI/INFORM Global.

[70] Francis, G., Fidato, A., & Humphreys, I. (2003). Airport-airline interaction: the impact of low-cost carriers on two European airports. *Journal of Air Transport Management, 9*(4), 267 - 273. Retrieved January 2, 2007 from Elsevier ScienceDirect database.

[71] Frankfurt-Hahn Airport (HHN). (2007). Official *website of the Airport Frankfurt Hahn*. Retrieved July 17, 2007 from http://www.hahn-airport.de/default.aspx?menu=traffic_data&cc=en.

[72] Frankfurt-Hahn Airport (HHN). (2007a). *Frankfurt Hahn Airport passes the operative break-even point*. Retrieved July 17, 2007 from http://www.hahn-airport.de/default.aspx?menu=news&cc=en&dataid=509550.

[73] Gannon, C., & Shalizi, Z. (1995). *The use of sectoral and project performance indicators in Bank-financed transport operations* (World Bank Report TWU 21). The World Bank Environmentally Sustainable Development Transportation, Water & Urban Development Department. Retrieved July 27, 2007, from http://www.worldbank.org/html/opr/pmi/transpor/trans.html.

[74] Gesner, G. A., & Jardim, J. (1998). Bridge within a bridge. *Civil Engineering – ASCE, 68* (10), 44-47.

[75] Gillen, D., & Lall, A. (2004). Competitive advantage of low-cost carriers: Some implications for airports. *Journal of Air Transport Management, 10* (1), 31 - 50. Retrieved January 2, 2007 from Elsevier ScienceDirect database.

[76] GRA Incorporated (2003). *Alternative airports study: Final report*. Retrieved online on July 17, 2007.

[77] Graf, L. (2005). Incompatibilities of the low-cost and network carrier business models within the same airline grouping. *Journal of Air Transport Management, 11* (5), 313 – 327. Retrieved January 2, 2007 from Elsevier ScienceDirect database.

[78] Graham, A. (2004). Airport strategies to gain competitive advantage: *German Aviation Research Seminar*, University of Bremen, Germany. Retrieved online on January 23, 2007 from http://www.garsonline.de/Downloads/Slots%20Competition%20Benchmarking/041119-graham.pdf.

[79] Hall, J. (2004, September 18). Requiem for an airport. *The Toronto Star*. Retrieved July 21, 2007 from Factiva database.

[80] Harvey, G. (1987). Airport Choice in a multiple airport region. *Transportation Research A, 21* (6), 439-449.

[81] Heyward, P. (2007). *Proposed design would change KCI*. Retrieved July 17, 2007 from http://www.webcitation.org/5Ng82ehOP.

[82] Hodota, K. (2006). *R&D and deployment valuation of intelligent transportation systems: A case example of the intersection collision avoidance systems*. Master's thesis. Massachusetts Institute of Technology. Cambridge, MA.

[83] Howard, L., & Keller, W. (n.d.). *Aviation System Planning: Addressing Airport Infrastructure Needs.* Retrieved May 03, 2007, from http://onlinepubs.trb.org/onlinepubs/millennium/00009.pdf.

[84] Ingersoll Jr., J., & Ross, S. (1992). Waiting to invest: Investment and uncertainty. *The Journal of Business, 65* (1), 1-29.

[85] International Air Transport Association (IATA). (2004). Airport *development reference manual: 9th Edition*. Geneva: IATA.

[86] International Air Transport Association (IATA). (2007). About us. Retrieved June 20, 2007, from <http://www.iata.org/about/>.

[87] International Air Transport Association (IATA). (2007a). *Airport development*. Retrieved June 20, 2007, from http://www.iata.org/whatwedo/airport-ans/airport-development.htm.

[88] International Civil Aviation Organization (ICAO). (1985). *Manual on air traffic forecasting: 2nd edition*. Montréal: ICAO.

[89] International Civil Aviation Organization (ICAO). (1997). *Strategy guiding international civil aviation into the 21st century*. Montréal: ICAO. Retrieved June 20, 2007 from http://www.icao.int/icao/en/sap1997_en.pdf.

[90] International Civil Aviation Organization (ICAO) (2006). *Airport Economics Manual: 2nd Edition.* Montréal: ICAO. Retrieved June 20, 2007 from http://www.icao.int/icaonet/dcs/9562/9562_en.pdf.

[91] jvdz.net. (n.d.). *Low-cost carriers – Europe: Theoretical framework*. Retrieved July 24, 2007, from http://www.jvdz.net/index2.html?/lcc-history.html&frameMain.

[92] Kansas City International Airport (MCI). (2007). *Interactive Airport Map*. Retrieved July 17, 2007 from http://www.flykci.com/AirportService/29/Index.htm.

[93] Kazda, A. & Caves, R. (2000). *Airport design and operation*. New York: Pergamon.

[94] Lindblom, C. E. (1959). The science of muddling through. *Public Administration Review, 19*, 79 – 88.

[95] Liverpool John Lennon Airport (2007). *Liverpool's Lord Mayor Salutes Record-Breaking Ryanair*. Retrieved July 17, 2007 from http://www.liverpooljohnlennonairport.com/page.php?p=3&offset=0&media_id=213.

[96] Lopes, V. (2005). *Viabilidade financeira do Novo Aeroporto de Lisboa. Banco Efiso*. Presented at the Lisbon 2017 Conference in Portugal on November 22, 2005 on behalf of Banco Efiso. Retrieved January 18, 2007, from http://www.naer.pt/portal/page/portal/NAER/Eventos/?CTEV=16661&actualmenu=18859&cboui=16661.

[97] Maldonado, J. (1990). *Strategic planning: An approach to improving airport planning under uncertainty*. Master's thesis. Massachusetts Institute of Technology, Cambridge, MA.

[98] McDonald, R., & Siegel, D. (1986). The value of waiting to invest. *The Quarterly Journal of Economics, 101* (4), 707 - 728.

[99] Mercer Management Consulting. (2002). *Low cost airlines gaining momentum in Europe*: Schneiderbauer, D. & Fainsilber, O. Retrieved January 2, 2007 from http://www.mercermc.com/Perspectives/Specialty/MOT_pdfs/3-Low-Cost%20Airlines.pdf.

[100] MITRE Corporation, The. (2007). *Capacity Needs in the National Airspace System 2007 – 2025: An Analysis of Airports and Metropolitan Area Demand and Operational Capacity in the Future*." Washington DC: FAA. Retrieved July 2, 2007 from http://www.faa.gov/airports_airtraffic/airports/resources/publications/reports/media/fact_2.pdf.

[101] Mittal, G. (2004). *Real options approach to capacity planning under uncertainty*. Master's thesis. Massachusetts Institute of Technology, Cambridge, MA.

[102] Morrell, P. (2005). Airlines within airlines: An analysis of US network airline responses to low-cost carriers. *Journal of Air Transport Management, 11* (5), 303-312. Retrieved January 4, 2007, from https://dspace.lib.cranfield.ac.uk/bitstream/1826/1232/1/ATRS+04-Airlines+within+airlines+Morrell.pdf.

[103] Munich Airport International. (2002). *Annual report 2002*. Retrieved July 17, 2007, from http://www.munich-airport.de/EN/Areas/Company/download/index.html.

[104] Munich Airport International. (2005). *Annual report 2005*. Retrieved July 17, 2007, from http://www.munich-airport.de/EN/Areas/Company/download/index.html.

[105] Novo Aeroporto S. A. (NAER). (1982). New Lisbon International Airport: Preliminary Planning Study Final Report, Volume 1 (5435/I). NAER. Retrieved January 2, 2007, from http://www.naer.pt/portal/page/portal/NAER/Estudos/?CTES=11356&actualmenu=6540&cboui=11356.

[106] Odoni, A., de Neufville, R. (1992). Passenger terminal design. *Transportation Research A, 26* (1), 27 - 35.

[107] Pantazis, N., & Liefner, I. (2006). The impact of low-cost carriers on catchment areas of established international airports: The case of Hanover Airport, Germany. *Journal of Transport Geography, 14* (4), 265 – 272. Retrieved online on January 4, 2007 from ScienceDirect database.

[108] Petkova, B. (2007). *Strategic planning for rail system design: An application for Portuguese high seed rail.* Master's thesis. University of Groningen, Groningen, Netherlands.

[109] Pitt, M. (2001). Strategic direction in the airport business: enabling or disabling? *Facilities, 19* (3/4), 150.

[110] Poole, J. (undated). *Airport and Air Navigation Charges*. Undated Presentation. Retrieved June 12, 2007, from http://www.iata.org/nr/rdonlyres/712fca53-2200-44bc-80ca-b6524efed1d1/0/airport_air_transport_charges.pdf.

[111] Port Authority of New York and New Jersey, The. (2006). *All airports*. Retrieved August 1, 2007, from http://www.kennedyairport.com/CommutingTravel/airports/html/index.html.

[112] Portugal, Government of. (2005). *Lisbon strategy – Portugal anew: National action programme for growth and jobs 2005/2008.* Retrieved August 7, 2007, from http://www.estrategiadelisboa.pt/document/1130508590H5cYI5th2Qi45CA4.pdf.

[113] Portugal, Government of. (2006). *Lisbon strategy – Portugal anew: National action programme for growth and jobs 2005/2008; Report on 1st year of implementation.* Retrieved August 7, 2007, from http://ec.europa.eu/growthandjobs/pdf/nrp/PT_nrp_en.pdf.

[114] Ragland, T. K., & Frost, K. G. (1998). Landside planning at ABIA. In M. McNerney (Ed.), *Airport facilities: Innovations for the next century: Proceedings of the 25th International air transportation conference*. Reston, Virginia, ASCE.

[115] Reiss, S. (1995).Down-to-Earth terminal design. *Civil Engineering*, *65* (2), 48 – 51.

[116] Reynolds-Feighan, A., & Button, K. (1999). An assessment of capacity and congestion levels at European airports. *Journal of Air Transport Management*, *5* (3), 113-134. Retrieved on January 17, 2007, from ScienceDirect online database.

[117] Savage, S. (2000, October 8). The flaw of averages. *San Jose Mercury News*. Retrieved August 1, 2007, from http://www.stanford.edu/~savage/flaw/Article.htm.

[118] Schwartz, A. C. (2004). Luring the LCCs. *Air Transport World, 41*(5): 38-42.

[119] Simon, H. (1955). *Administrative behavior*. New York: MacMillan & Co.

[120] Skytrax (2007). *Airport of the Year 2006*. Retrieved July 17, 2007 from http://www.worldairportawards.com/Awards-2006/AirportYear-2006.htm.

[121] Trani, A. A. (2002). *Airport Landside Analysis and Modeling*. Retrieved July 16, 2007 from http://128.173.204.63/courses/cee4674/cee4674_pub/airport_landside.pdf.

[122] United Kingdom Civil Aviation Authority (CAA). (2003). *The future development of air transport in the United Kingdom.* Retrieved July 02, 2007, from http://www.caa.co.uk/docs/1/erg_erg_Futuredevofairtransport.pdf.

[123] United States Federal Aviation Administration (FAA). (1989). *Advisory circular: Airport design* (AC No: 150/5300-13). Retrieved on August 3, 2007 from http://www.faa.gov/airports_airtraffic/airports/resources/advisory_circulars/media/150-5300-13/150_5300_13_part1.pdf.

[124] United States Federal Aviation Administration (FAA). (1997). *Report to Congress on potential for use of land options in federally funded airport projects*. Retrieved July 17, 2007, from http://www.faa.gov/airports_airtraffic/airports/aip/media/land_options.pdf.

[125] United States Federal Aviation Administration (FAA) (2003). *2003 ACE plan: Aviation capacity enhancement plan.* Retrieved July 2, 2007, from http://www.faa.gov/airports_airtraffic/airports/resources/advisory_circulars/media/150-5070-6B/150_5070_6b_chg1.doc.

[126] United States Federal Aviation Administration (FAA). (2005). *Advisory circular: Airport master plans.* Retrieved July 2, 2007, from http://www.faa.gov/airports_airtraffic/airports/resources/advisory_circulars/media/150-5070-6B/150_5070_6b_chg1.doc.

[127] United States Federal Aviation Administration (FAA). (2006). *National plan of integrated airport systems (NPIAS), 2007 – 2011.* Retrieved July 17, 2007, from http://www.faa.gov/airports_airtraffic/airports/planning_capacity/npias/reports/media/2007/npias_2007_narrative.pdf.

[128] United States Federal Aviation Administration (FAA). (2007). *2008 – 2012 flight plan (redline draft)*. Retrieved August 3, 2007, from http://www.faa.gov/about/plans_reports/media/Draft_Flight_Plan_06132007.pdf.

[129] United States Office of Management of Budget (OMB). (2003). *Circular A-4*. Retrieved on August 3, 2007, from http://www.whitehouse.gov/omb/circulars/a004/a-4.pdf.

[130] Wang, T., & de Neufville, R. (2006). *Identification of real options "in" projects*. 16th Annual International Symposium of the International Council on Systems Engineering (INCOSE), Orlando, Florida. Retrieved on August 3, 2007, from http://ardent.mit.edu/real_options/Real_opts_papers/Identification%20of%20Real%20Option%20in%20Projects%20INCOSE.pdf.

[131] Warnock-Smith, D., & Potter, A. (2005). An exploratory study into airport choice factors for European low-cost airlines. *Journal of Air Transport Management, 11* (6), 368-392. Retrieved January 4, 2007, from Elsevier ScienceDirect database.

A. APPENDICES

A1. The New Airport Runway Model: A Simple Binomial Lattice

Determining how much runway capacity to construct at a new airport is an important element for ensuring success. Too little capacity leaves demand un-served; too much capacity represents waste. Given that the development of traffic over time cannot be known beforehand with certainty, methods for modeling growth are quite useful. The binomial lattice provides a simple means of showing the possible traffic levels and the associated probabilities each.

<u>System Development</u>

Binomial lattices are capable of modeling uncertain trends, so long as those trends may be assumed to have a constant average rate of growth. Two simplifications underlie the model. First, lattices assume that the uncertain factor being modeled can change in only one of two ways – increase or decrease by fixed multiplicative factors – during any given time increment or period. If the period is small compared to the total length of time being analyzed, the model provides acceptable results despite its underlying simplification.

Second, lattices assume path independence. Starting from the same period, an increase followed by a decrease in the uncertain parameter leads to the same result as a decrease followed by an increase. This requires that the value of the increase factor is the inverse of the value of the decrease factor, as explained further on.

This set-up leads to the strength of the binomial lattice. Assuming that the system may only evolve in one of two ways during each period reduces the complexity of the problem. Moreover, path independence causes the lattice to recombine. Without this assumption, ten periods with two possible outcomes after each one would lead to some 2^10 possibilities at the end of the analysis. Recombination, however, reduces the total number of possibilities to 10.

In the case of the New Airport Runway Model, the uncertain factor being considered is the demand for passenger traffic. Twenty-five periods, with each period representing one year, are considered. As presented in Figure A-1, a single initial demand (in yellow) yields twenty-five different possible demand levels (in red) by the end of the analysis. The lattice presented represents fabricated data for the New Lisbon International Airport (here referred to as NLA) in Portugal.

Year 1	Year 2	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 24	Year 25
6,000	7,034	21,408	25,097	29,422	34,493	40,438	47,407	55,576	65,154	232,470	272,533
	5,118	15,576	18,261	21,408	25,097	29,422	34,493	40,438	47,407	169,146	198,296
		11,333	13,287	15,576	18,261	21,408	25,097	29,422	34,493	123,071	144,281
		8,246	9,667	11,333	13,287	15,576	18,261	21,408	25,097	89,547	104,979
		6,000	7,034	8,246	9,667	11,333	13,287	15,576	18,261	65,154	76,383
		4,366	5,118	6,000	7,034	8,246	9,667	11,333	13,287	47,407	55,576
		3,176	3,724	4,366	5,118	6,000	7,034	8,246	9,667	34,493	40,438
		2,311	2,709	3,176	3,724	4,366	5,118	6,000	7,034	25,097	29,422
		1,682	1,971	2,311	2,709	3,176	3,724	4,366	5,118	18,261	21,408
			1,434	1,682	1,971	2,311	2,709	3,176	3,724	13,287	15,576
				1,224	1,434	1,682	1,971	2,311	2,709	9,667	11,333
					1,044	1,224	1,434	1,682	1,971	7,034	8,246
						890	1,044	1,224	1,434	5,118	6,000
							759	890	1,044	3,724	4,366
								648	759	2,709	3,176
									553	1,971	2,311
										1,434	1,682
										1,044	1,224
										759	890
										553	648
										402	471
										293	343
										213	250
										155	182
											132

All values in thousands of passengers.

Figure A-1: New Airport Runway Model - Sample Demand Lattice

In order to fully consider the development of traffic, a second lattice is required in order to calculate the probability of each demand state. According to Figures A – 2 and A-3, the probability of arriving at the highest level of demand in Year 25, 272 million passengers per year, is highly unlikely. However, there is an 18% chance that 40 million passengers will require air transportation services (circled in green).

Year 1	Year 2	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 24	Year 25
1.00	0.72	0.07	0.05	0.04	0.03	0.02	0.01	0.01	0.01	0.00	0.00
	0.28	0.23	0.19	0.15	0.12	0.09	0.07	0.06	0.04	0.01	0.00
		0.31	0.29	0.26	0.23	0.20	0.17	0.14	0.12	0.02	0.02
		0.23	0.25	0.26	0.26	0.25	0.24	0.22	0.20	0.06	0.05
		0.11	0.15	0.18	0.20	0.22	0.23	0.23	0.23	0.11	0.10
		0.03	0.06	0.08	0.11	0.13	0.16	0.18	0.19	0.16	0.15
		0.01	0.01	0.03	0.04	0.06	0.08	0.10	0.12	0.18	0.18
		0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.06	0.17	0.17
		0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.13	0.14
			0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.08	0.10
				0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.06
					0.00	0.00	0.00	0.00	0.00	0.02	0.03
						0.00	0.00	0.00	0.00	0.01	0.01
							0.00	0.00	0.00	0.00	0.00
								0.00	0.00	0.00	0.00
									0.00	0.00	0.00
										0.00	0.00
										0.00	0.00
										0.00	0.00
										0.00	0.00
										0.00	0.00
										0.00	0.00
										0.00	0.00
										0.00	0.00
											0.00

Figure A-2: New Airport Runway Model - Sample Probability Lattice

A2. The New Airport Runway Model: Inputs and Instructions for use

Entries Form A

Entries Form A accepts the user inputs required to create the demand and probability binomial lattices. Required inputs include initial passenger demand, the average growth rate of passenger traffic, and the standard deviation in actual year-to-year growth. It also calculates the increase and decrease factors for both lattices.

Observed Passenger Data

Observed Passenger Data				Default Value	[ ]	% of S
Initial Demand	*S*	=	6,000,000	6,000,000	pax	
Standard Deviation	*D*	=	15.90%	15.90%	%/yr	
Average Growth Rate	*R*	=	7.10%	7.10%	%/yr	

Figure A-3: New Airport Runway Model - Default Passenger Data

The default value of the initial demand used assumes that the New Lisbon International Airport will serve one-half of the region's forecast traffic upon its opening in 2017. The average growth rate of 7.10% per year has been derived from sample data from Washington Dulles International Airport (IAD) during one of its growth periods. IAD data also provides the standard deviation of yearly rates of growth. Dulles data was used because it – as presumably NLA will – experienced rapid growth after the introduction of multiple key carriers. Although the average rate used is less than the current growth being experienced at Portela, these inputs provide forecasts which closely match those presumed for the new airport. This can be shown by calculating the expected level of passenger traffic in Year 22, when NLA is forecast to support 33 million passengers (BPCC, 2007).

Equation A-1: New Airport Runway Model – Calculation of Expected Passengers per Year

$$\text{Expected Passengers in Year 22} = \sum_{1}^{22} (\text{Probabilities} \mid \text{Year 22}) * (\text{Demand Levels} \mid \text{Year 22})$$

$$\text{Expected Passengers in Year 22} = (0.00*273) + (0.00*198) + (0.02*144) + (0.05*105) + \ldots + (0.00*.132) \text{ million passengers}$$

$$\text{Expected Passengers in Year 22} = 32.6 \text{ million passengers}$$

Probability Data

Additional Terms					
				Default Value	[ ]
Starting Probability	P	=	100%	100	%
Time Step	Δt	=	1	1	yr
Discount Rate	DR	=	12%	12	%

Figure A-4: New Airport Runway Model - Additional Default Values

The model further accepts data as to the certainty that the starting demand input is correct. In this case, the information is assumed to be accurate; the initial demand occurs with 100% surety. Each time increment is assumed to represent one year. A discount rate of 12%, which is typical for government applications, is applied to all revenue estimates.

Finally, Entries Form A calculates the values of the multiplicative increase and decrease factors which are applied to both the demand and probability lattices.

Calculated Parameters		
Increase Factor	***u* =**	1.17
Decrease Factor	***d* =**	0.85
Probability Increase Factor	***p* =**	0.72
Probability Decrease Factor	**1 - *p* =**	0.28

Figure A-5: New Airport Runway Model - Default Lattice Multiplicative Factors

Equation A-2: New Airport Runway Model - Calculation of Lattice Multiplicative Factors

$$\text{Growth Rate} = v$$

$$\text{Volatility} = \sigma$$

$$\text{Time increment (length of period)} = \Delta\text{t}$$

$$\text{Increase Factor} = u = e^{\sigma\sqrt{\Delta t}}$$

$$\text{Decrease Factor} = d = e^{-\sigma\sqrt{\Delta t}}$$

$$\text{Probability Increase Factor} = p = .5 + .5\left(\frac{v}{\sigma}\right)\sqrt{\Delta t}$$

$$\text{Probability Decrease Factor} = 1 - p$$

Entries Form B

Entries Form B allows the user to give information required to calculate airport revenues.

Revenue Streams and Aircraft Mix

Revenues Streams by Aircraft Weight

MTOW min [mt]	MTOW max [mt]	Landing Fees [$/mt]	Parking Fees [$/24 hrs]
0	25	31	205
25	200	34	308
200	*max*	21	513

mt = metric tonne; parking fees accrued per 24 hrs or part thereof
Default values stored in Entries B (Default)

Aircraft Mix

	Avg. Capacity [pax]	MTOW [mt]	% Movements [% Total]	Revenue/ Movement [$]
B737-500	115.0	52.6	20.00%	$342.49
A320-200	162.0	73.9	30.00%	$342.49
B757-200	190.0	109.3	20.00%	$342.49
B747-400	382.0	398.3	30.00%	$533.53
			100.00%	

Default values stored in Entries B (Default)

Figure A-6: New Airport Runway Model - Default Values for Landing/Parking Fees and Aircraft Mix

Revenue streams are determined based on a modifiable hypothetical aircraft mix at the new airport. Using the hypothetical aircraft mix and assumptions as to what percentage of runway movements are served by each aircraft, the New Airport Runway Model determines how many landings per year are required in order to serve passenger demand.

Equation A-3: New Airport Runway Model – Calculation of Landings Required

$$\text{Landings Required} = \frac{\text{Passenger Demand}}{\sum_{1}^{aircraft}(\text{Average Aircraft Capacity} * \%\ \text{Movements Served by Aircraft})}$$

This figure – the number of landings as bounded by the airside capacity – then translates into a revenue figure. In this case, airside revenue is assumed to compose of landing fees per metric ton and one hour of parking fees per aircraft only. Default fee values have been adapted from sample information provided by Cardiff International Airport in the UK (CWL, 2007). The sample aircraft mix is purely hypothetical.

Equation A-4: New Airport Runway Model – Calculation of Revenue per Year

$$\text{Aircraft Revenue per Landing} = \text{Aircraft MTOW} * \text{Landing Fee} + \text{Parking Fee}$$

$$\text{Total Revenue} = \text{MAX}(\text{Landings Required, Runway Capacity}) * \left(\sum_{1}^{Aircraft} \text{Percentage of Movements per Aircraft} * \text{Aircraft Revenue per Landing} \right)$$

Runway Data

Finally, the New Airport Runway Model calls for information on runway capital costs, operating expenditures, and maximum capacities. This data allows for the determination of net income calculations.

Runway 1			Default Value	[ ]
Period Operationalized	a	1	1	yr = 1
Maximum Landings	b	95,000	95,000	#
Capital Costs (CC)	c	200,000,000	200,000,000	$
Payback Time (CC)	d	25	25	yr
Operating Costs	e	3,000,000	3,000,000	$

Runway 2			Default Value	[ ]
Period Operationalized	a	1	**1**	0 < yr < 25
Maximum Landings	b	95,000	95,000	#
Capital Costs (CC)	c	200,000,000	200,000,000	$
Payback Time (CC)	d	25	25	yr
Operating Costs	e	3,000,000	3,000,000	$

Default values assume that each runway can support approximately 95,000 landings in a given year, thereby serving some 21 million passengers per annum given the input parameters. This data correlates closely with actual traffic values at London/Stansted Airport (LTN), which serves nearly 24 million passengers per year using a single runway.

Runway 1 is opened in Year 1 of airport operation by default. This value is fixed. The input value regarding opening Runway 2 is also Year 1. This value is also fixed. However, the New Airport Runway Model determines the best year to operationalize Runway 2.

Capital costs are repaid in equal increments over twenty-five years regardless of when the runway comes online. Operating costs are assumed to be US $3 million per year.

Free Calc

The "Free Calc" tab, using the default data input in Entries Forms A and B, determines the best year to construct a second runway given the total set of probable demand levels. Further, it allows the user to directly vary in what year Runway 2 is opened. This user input is accepted in the white cell shown in Figure A-7. Choosing to operationalize Runway 2 after Period 25 has no effect on the model; it simulates a scenario in which the second runway is not constructed at all.

Second Runway	
Period Operationalized	26
Movements/Runway	95,000
Cost/Runway ($)	200,000,000
Payback Time (yrs)	25
Capital Costs/Annum	8,000,000
Operating Costs ($)	3,000,000

Figure A-7: New Airport Runway Model - Free Calc Sample Input

Quick Results

The "Free Calc" tab is divided into several areas. The first division presents quick results regarding the value of the Airside as a function of the user input data. Further, it suggests the best year to open the second runway in order to maximize profit and passengers served.

Quick Results: Graphical Representations & Interpretation
If Runway 2 is constructed in Period 26, Airside Value = $ 35 million.
To Maximize Profit, Build in Period 18.
To Maximize Pax Served, Build in Period 9.

Figure A-8: New Airport Runway Model - Sample Results

Basic Binomial Lattices

The second division reproduces the binomial lattices which calculate total passenger demand and the probability of each.

Construction Limited Lattices

The third division applies Equations A-3 to the demand lattice in order to determine the total number of landings required to serve the passenger demand and the actual passengers served given capacity limitations. Figure A-9 presents the lattice showing the actual number of passengers served. Reddened cells indicate that the total number of passengers served, given only one runway, is limited by airside capacity.

Year 1	Year 2	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 24	Year 25
6,000	7,034	21,299	21,299	21,299	21,299	21,299	21,299	21,299	21,299	21,299	21,299
	5,118	15,576	18,261	21,299	21,299	21,299	21,299	21,299	21,299	21,299	21,299
		11,333	13,287	15,576	18,261	21,299	21,299	21,299	21,299	21,299	21,299
		8,246	9,667	11,333	13,287	15,576	18,261	21,299	21,299	21,299	21,299
		6,000	7,034	8,246	9,667	11,333	13,287	15,576	18,261	21,299	21,299
		4,366	5,118	6,000	7,034	8,246	9,667	11,333	13,287	21,299	21,299
		3,176	3,724	4,366	5,118	6,000	7,034	8,246	9,667	21,299	21,299
		2,311	2,709	3,176	3,724	4,366	5,118	6,000	7,034	21,299	21,299
		1,682	1,971	2,311	2,709	3,176	3,724	4,366	5,118	18,261	21,299
			1,434	1,682	1,971	2,311	2,709	3,176	3,724	13,287	15,576
				1,224	1,434	1,682	1,971	2,311	2,709	9,667	11,333
					1,044	1,224	1,434	1,682	1,971	7,034	8,246
						890	1,044	1,224	1,434	5,118	6,000
							759	890	1,044	3,724	4,366
								648	759	2,709	3,176
									553	1,971	2,311
										1,434	1,682
										1,044	1,224
										759	890
										553	648
										402	471
										293	343
										213	250
										155	182
											132

All values in thousands of passengers

Figure A-9: New Airport Runway Model - Capacity Limited Passengers Served/Yr

Revenue Development

The fourth division applies Equations A-4 to show the expected revenue associated with each level of passenger demand and the expected value of revenue in each year.

Further, this division calculates the total expected value of the airside system over twenty-five years. This value is presented in the first cell.

The airside value is calculated by working backwards through the lattice. The last column of cells presents actual revenues associated with each possible level of demand in the last period. Each preceding cell presents the sum of the probability weighted revenue of the next year and the revenue provided by the level of demand corresponding to that cell.

Equation A-5 presents the calculation, using Figures A-10 and A-11 as an example.

Year 24	Year 25
$ 24,090	$ 24,090
$ 24,090	$ 24,090
$ 24,090	$ 24,090
$ 24,090	$ 24,090
$ 24,090	$ 24,090
$ 24,090	$ 24,090
$ 24,090	$ 24,090
$ 24,090	$ 24,090
$ 19,253	$ 24,090
$ 11,333	$ 14,979
$ 5,571	$ 8,223
$ 1,378	$ 3,308
$ 1,673	$ 268
$ 3,892	$ 2,871
$ 5,507	$ 4,764
$ 6,683	$ 6,142
$ 7,538	$ 7,144
$ 8,160	$ 7,873
$ 8,612	$ 8,404
$ 8,942	$ 8,790
$ 9,181	$ 9,071
$ 9,356	$ 9,275
$ 9,483	$ 9,424
$ 9,575	$ 9,532
	$ 9,611

Figure A-10: Revenue Development

Year 24	Year 25
$ 40,529	$ 21,412
$ 40,529	$ 21,412
$ 40,529	$ 21,412
$ 40,529	$ 21,412
$ 40,529	$ 21,412
$ 40,529	$ 21,412
$ 40,529	$ 21,412
$ 40,529	$ 21,412
$ 33,441	$ 21,412
$ 17,968	$ 12,300
$ 6,629	$ 5,545
$ 1,622	$ 630
$ 7,625	$ 2,947
$ 11,993	$ 5,549
$ 15,172	$ 7,443
$ 17,484	$ 8,820
$ 19,166	$ 9,823
$ 20,391	$ 10,552
$ 21,281	$ 11,083
$ 21,930	$ 11,469
$ 22,401	$ 11,750
$ 22,744	$ 11,954
$ 22,994	$ 12,103
$ 23,176	$ 12,211
	$ 12,290

Figure A-11: Airside Value

Equation A-5: Calculation of Airside Values

$$\text{Value (Year 24, Cell 1)} = \text{Prob\_up} * \text{Revenue(Year 25, Cell 1)} + \text{Prob\_down} * \text{Revenue (Year 25, Cell 2)} + \text{Revenue (Year 24, Cell 1)} \ \ [\text{k\$}]$$

$$\text{Value (Year 24, Cell 1)} = .72 * 21{,}412 + .28 * \$21{,}412 + .\$24{,}090 \ \ [\text{k\$}]$$

Expected Value Lattices

The fifth division gives the probability-weighted number of passengers served at each level of demand.

Equation A-6: Calculation of Expected Passengers Served

$$\begin{aligned} &\text{E(Passengers Served | Year x, Cell y)} = \text{Probability (Year x, Cell y)} * \\ &\qquad \text{Min (Airside Capacity in passengers, Passenger Demand | Year x, Cell y)} \end{aligned}$$

Graphical Representations and Interpretations

Finally, the last division provides advice regarding the best year to open the second runway in order to maximize the expected passengers served and expected airside value. The New Airport Runway Model will always suggest constructing a second runway as soon as the possibility of capacity-limitations exists. However, the year-to-open in order to maximize revenue considers all possible growth rates and probabilities.

<u>No Expansion Calc</u>

The "No Expansion Calc" tab replicates the values in the "Free Calc" tab assuming that the second runway is never constructed.

<u>Expansion Calc</u>

The "Expansion Calc" tab replicates the values in the "Free Calc" tab assuming that the second runway is operationalized during the first period, Year 1.

<u>Option Calc</u>

The "Option Calc" tab determines the value of the option to expand when the demand level and probability of increased revenue require it. This calculation requires three lattices. The first lattice replicates the determination of airside value in the "No Expansion Calc" tab; it assumes that a second runway is never completed. The second lattice replicates the determination of airside value in the "Expansion Calc" tab.

Finally, the third lattice is created by comparing the values in each cell of the preceding two, starting with the column in the final period, Year 25. At each preceding cell, the Runway Model determines whether having a second runway would increase the net income. If so, the Runway Model assumes that the runway is opened. Figures A-12 through A-14 illustrate. A-14 shows instances where it is best to open a second runway in green.

Year 1	Year 2	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 24	Year 25
$ 59	$ 76	$ 187	$ 187	$ 183	$ 179	$ 173	$ 167	$ 160	$ 152	$ 46	$ 24
	$ 40	$ 160	$ 172	$ 179	$ 177	$ 173	$ 167	$ 160	$ 152	$ 46	$ 24
		$ 121	$ 138	$ 152	$ 163	$ 169	$ 166	$ 160	$ 152	$ 46	$ 24
		$ 80	$ 97	$ 113	$ 129	$ 142	$ 152	$ 156	$ 151	$ 46	$ 24
		$ 43	$ 58	$ 73	$ 89	$ 104	$ 118	$ 130	$ 138	$ 46	$ 24
		$ 13	$ 25	$ 37	$ 51	$ 65	$ 79	$ 92	$ 105	$ 46	$ 24
		$ 12	$ 2	$ 8	$ 19	$ 31	$ 43	$ 55	$ 68	$ 46	$ 24
		$ 30	$ 22	$ 14	$ 5	$ 4	$ 14	$ 24	$ 34	$ 46	$ 24
		$ 43	$ 37	$ 31	$ 24	$ 16	$ 8	$	$ 8	$ 39	$ 24
			$ 48	$ 43	$ 37	$ 31	$ 25	$ 18	$ 11	$ 23	$ 15
				$ 51	$ 47	$ 42	$ 36	$ 31	$ 25	$ 12	$ 8
					$ 54	$ 50	$ 45	$ 40	$ 35	$ 3	$ 3
						$ 55	$ 51	$ 47	$ 42	$ 3	$
							$ 56	$ 52	$ 48	$ 7	$ 3
								$ 56	$ 52	$ 10	$ 5
									$ 55	$ 12	$ 6
										$ 14	$ 7
										$ 15	$ 8
										$ 16	$ 8
										$ 17	$ 9
										$ 17	$ 9
										$ 18	$ 9
										$ 18	$ 9
										$ 18	$ 10
											$ 10

All values in millions of dollars.
All values in present dollars for that year.

Figure A-12: New Airport Runway Model - Airside Value without 2nd Runway

Year 1	Year 2	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 24	Year 25
$ 12	$ 10	$ 227	$ 260	$ 291	$ 315	$ 330	$ 329	$ 319	$ 305	$ 91	$ 48
	$ 36	$ 146	$ 179	$ 211	$ 243	$ 271	$ 292	$ 304	$ 300	$ 91	$ 48
		$ 74	$ 103	$ 132	$ 163	$ 193	$ 221	$ 246	$ 264	$ 91	$ 48
		$ 15	$ 38	$ 63	$ 89	$ 117	$ 144	$ 171	$ 195	$ 91	$ 48
		$ 30	$ 12	$ 8	$ 29	$ 51	$ 75	$ 98	$ 122	$ 91	$ 48
		$ 65	$ 50	$ 35	$ 18	$	$ 19	$ 38	$ 58	$ 90	$ 48
		$ 90	$ 78	$ 66	$ 53	$ 38	$ 23	$ 7	$ 9	$ 71	$ 45
		$ 108	$ 99	$ 89	$ 78	$ 66	$ 54	$ 41	$ 27	$ 41	$ 27
		$ 121	$ 114	$ 105	$ 97	$ 87	$ 76	$ 65	$ 54	$ 20	$ 14
			$ 125	$ 118	$ 110	$ 102	$ 93	$ 83	$ 73	$ 4	$ 5
				$ 126	$ 120	$ 112	$ 105	$ 96	$ 87	$ 7	$ 2
					$ 127	$ 120	$ 113	$ 105	$ 97	$ 15	$ 7
						$ 126	$ 120	$ 112	$ 105	$ 21	$ 10
							$ 124	$ 117	$ 110	$ 26	$ 13
								$ 121	$ 114	$ 29	$ 15
									$ 117	$ 31	$ 16
										$ 33	$ 17
										$ 34	$ 18
										$ 35	$ 18
										$ 35	$ 19
										$ 36	$ 19
										$ 36	$ 19
										$ 37	$ 19
										$ 37	$ 19
											$ 19

All values in millions of dollars.
All values in present dollars for that year.

Figure A-13: New Airport Runway Model - Airside Value with 2nd Runway Opened in Year 1

Year 1	Year 2	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 24	Year 25
$ 67	$ 86	$ 252	$ 270	$ 291	$ 315	$ 330	$ 329	$ 319	$ 305	$ 91	$ 48
	$ 45	$ 194	$ 217	$ 237	$ 253	$ 271	$ 292	$ 304	$ 300	$ 91	$ 48
		$ 137	$ 159	$ 180	$ 201	$ 218	$ 231	$ 246	$ 264	$ 91	$ 48
		$ 86	$ 105	$ 125	$ 145	$ 164	$ 181	$ 196	$ 205	$ 91	$ 48
		$ 45	$ 61	$ 77	$ 94	$ 112	$ 129	$ 145	$ 159	$ 91	$ 48
		$ 13	$ 25	$ 38	$ 52	$ 67	$ 82	$ 97	$ 111	$ 90	$ 48
		$ 11	$ 2	$ 8	$ 20	$ 31	$ 44	$ 56	$ 69	$ 71	$ 45
		$ 30	$ 22	$ 14	$ 5	$ 4	$ 14	$ 24	$ 35	$ 48	$ 27
		$ 43	$ 37	$ 31	$ 24	$ 16	$ 8	$	$ 8	$ 39	$ 24
			$ 48	$ 43	$ 37	$ 31	$ 25	$ 18	$ 11	$ 23	$ 15
				$ 51	$ 47	$ 42	$ 36	$ 31	$ 25	$ 12	$ 8
					$ 54	$ 50	$ 45	$ 40	$ 35	$ 3	$ 3
						$ 55	$ 51	$ 47	$ 42	$ 3	$
							$ 56	$ 52	$ 48	$ 7	$ 3
								$ 56	$ 52	$ 10	$ 5
									$ 55	$ 12	$ 6
										$ 14	$ 7
										$ 15	$ 8
										$ 16	$ 8
										$ 17	$ 9
										$ 17	$ 9
										$ 18	$ 9
										$ 18	$ 9
										$ 18	$ 10
											$ 10

All values in millions of dollars.
All values in present dollars for that year.

Figure A-14: New Airport Runway Model - Airside Value with Option to Expand

A3. The Airport Terminal Model: A Simple Decision Tree

The creation of a successful terminal at The New Lisbon International Airport, as at many new airports, is subject both to several customer demands and to various uncertainties. Were the full list of airlines serviced, government security requirements, passenger demands, and an hourly traffic breakdown to be known beforehand, the design of the terminal would be greatly simplified. Indeed, designers could then fulfill most customer requirements and correctly size the airport such that no money was wasted on unused space and no opportunity forfeited due to overly small facilities. Unfortunately for the new airport's designers, however, no such prior information is available. To the contrary, increasing competition from low-cost carriers, the restructuring of Portugal's national carriers, and unknowns such as the future of Lisbon Portela Airport (LIS) and the economic growth of Portugal as a whole greatly cloud any prediction of customer demands and traffic levels. The development of the New Lisbon International Airport (here referred to as NLA) terminal facility therefore provides an opportunity to demonstrate the value of flexibility in airport design.

Decision tree modeling seems particularly appropriate for this analysis. Decision trees allow for the consideration of two important factors. First, they are capable of accounting for a large set of uncertainties, the contents of which are limited only by the available computational power. Therefore, this method of analysis can account not only for uncertainties regarding traffic growth but also for unanswered questions regarding the demands of the airline customer, political initiatives, and changing public preferences for travel. In essence, decision trees give planners an almost unlimited ability to model the effects of uncertainty. Second, decision trees allow for the possibility that managers can make logical decisions to deal with changing conditions. The tree recognizes, then, that the effects of probabilistically determined events can be mitigated by intelligent decision-making. Finally, decision tree models are capable of using information about future probabilistic events and decisions in order to advise planners who must make decisions in the present. This capability is quite potent. Tree analysis neither requires foreknowledge of future events nor does it attempt to identify most likely scenarios. Rather, it isolates those decision paths with the greatest likelihood of providing success in light of a world of unknowns.

Conversely, it should be noted that the New Airport Terminal Model, being tree-based, must be susceptible to the difficulties associated with decision tree analyses. Most important among these, variations in the probabilities of chance events input into the Terminal Model will affect its results; although the best decision path may not change, estimates of profitability likely will.

<u>System Development: Period I</u>

As detailed above, several uncertainties may affect the design of a successful terminal structure at The New Lisbon International Airport. These include the availability of external funding from the European Union, the lifetime of LIS after NLA opens, the trends governing low-cost and network carriers in the airport region, and the overall strength of the air transportation industry in Portugal. Modeling each of these possibilities in a decision tree would quickly yield a "messy bush" wherein the number of individual nodes grows exponentially with each new building alternative or chance outcome. Some simplifications are required.

In order to limit complexity, the New Airport Terminal Model considers only two major uncertainties. Correspondingly, it allows for two points at which airport planners and managers may make build decisions critical to airport success. Twenty-five years of airport operations, broken down into a ten year increment (Period I) and a 15 year increment immediately following (Period II) are modeled. The following subsections describe each period in detail. Figure A-1 encapsulates the concepts graphically.

Period	Timeframe	Uncertainty	Design Decision
I			
	0 - 10 years	Customer typed served *International or Domestic?* *Low cost or network?* *Short haul or long haul?*	How to build.
II			
	10 - 15 years	Traffic Growth Rate *Low, medium, or high traffic growth?* *Level of competition from other modes?*	How to build.

Figure A-15: New Airport Terminal Model - Period Specific Details

Period I: Who will provide the majority of New Airport traffic?

During the first twenty years since the airport's opening, Period I, the New Airport Terminal Model examines uncertainty regarding which group will provide for the majority of airport traffic. The Terminal Model assumes that only two major possibilities exist. This assumption matches well with normal airport dichotomies: traffic is often either international or domestic, direct or transfer, low-cost or network, etc. Although the user may select any combination, the following description assumes that competition between low-cost carriers and traditional network carriers will provide the most important uncertainty at the new airport. This also holds true for the Lisbon Airport Scenario presented in Chapter 5.

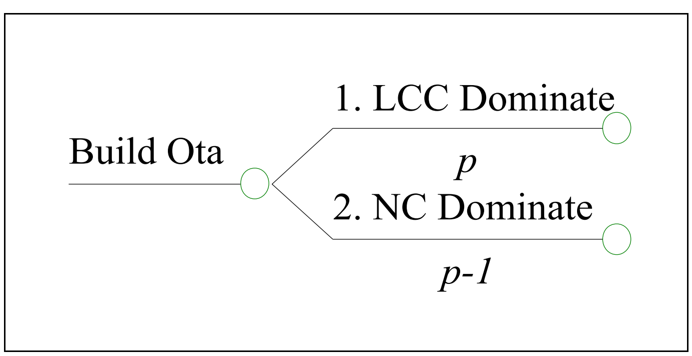


Figure A-16: Period I Chance Outcomes

Thus, given that The New Lisbon International Airport is constructed, the airport will either primarily serve low-cost carriers with probability, *p*, or network carriers with probability (*p-1*). The two chance outcomes imply very different revenue streams and cost structures for the airport.

Table A-1: Description of Chance Outcomes

Chance Event	Assumption
1. LCC Dominate	1. Low cost carriers become the dominant air transport service providers in and out of Europe. 2. The power of the Portuguese national carrier is curtailed.
2. NC Dominate	1. The current power of the network carriers in Portugal and around Europe is maintained 2. Portugal's national carrier and other network carriers dominate traffic in and out of NLA airport. 3. The power of the low-cost carrier is curtailed.

LCC Dominate (Outcome 1)

This chance outcome assumes that low-cost carriers become the dominant air transportation service providers throughout Europe and, subsequently, for Portugal. It thereby simulates the reduction in influence of the European network carriers and of Portugal's national carrier, TAP. This outcome would concur with predictions as to the continued growth of the low-cost carrier throughout Europe (Mercer, 2002, among others). Further, Outcome 1 may be construed as accounting for the real possibility that NLA could provide a prime candidate for low-cost service by allowing LCC to bypass the more crowded Portela airport when flying passengers into Lisbon in the years before Portela is slated to close. Given this outcome, NLA airport will prove most successful if it is constructed to suit the needs of the low-cost carrier.

NC Dominate (Outcome 2)

This chance outcome assumes that a situation more similar to the status quo, wherein the national carrier and larger network carriers dominate transportation at Portela airport, continues at NLA airport. Given this outcome, The New Lisbon International Airport will prove most successful if it is constructed to the specifications of the network carriers.

Construction Alternatives

The New Airport Terminal Model provides airport planners with three separate construction alternatives at the beginning of Period I. Appropriate use of the Terminal Model assumes that each alternative is keyed to handling uncertainties regarding the type of traffic served by the airport. Again, the description below assumes that the primary uncertainty deals with the competition between low-cost and traditional network carriers.

However, users can modify the Terminal Model to represent several different possibilities.

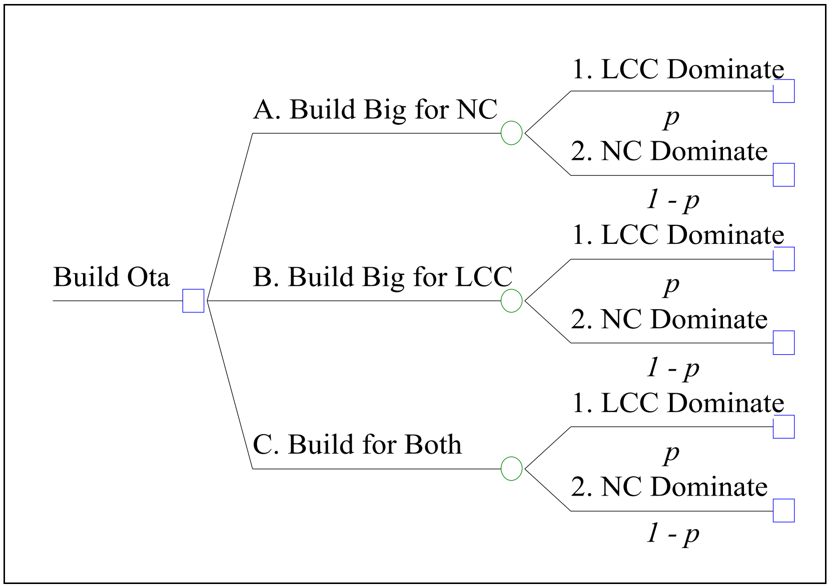


Figure A-17: Period I Alternatives and Chance Outcomes

Figure A-17 reveals three possible construction alternatives which airport designers may choose without prior knowledge of which chance outcome – LCC dominate or NC dominate – will come to pass. These alternatives match those modeled in the Lisbon Airport Scenario presented in Chapter 5. The alternatives are either building a large airport akin to Portela to support the network carriers (A), building a large airport to accommodate mainly low-cost carriers (B), or to delay the decision on which group of carriers to support by building a smaller airport to support both in the short run (C). The Terminal Model assumes that the chance outcome is unaffected by this choice during the first period. This assumption is not without merit; if the primary uncertainty is which carrier-type will dominate European air travel, it is unlikely that the construction of a single airport in Portugal would have a significant impact on the resolution of that question on a Europe-wide level.

Alternative C, constructing a smaller airport meant to host both LCC and NC, represents two real options concepts. First, it allows planners to defer their decisions on which carrier to build for. Second, it espouses the principle of incremental development by stressing the gradual development of the facility.

Table A-2: Description of Period I Alternatives

Alternative Name	Description
A. Build Big for NC	1. Large NC-focused facility comparable to Portela 2. Bulk of facility built immediately
B. Build Big for LCC	1. Large LCC-focused facility 2. Built to accommodate a surge of LCC traffic (and the decline of the national carrier) in Portugal 3. Bulk of facility built immediately
C. Build for Both NC and LCC	1. Smaller facility 2. Partially designed to accommodate moderate growth in network carriers at NLA 3. Partially designed to accommodate moderate growth in low-cost carriers at NLA

Build Big for Network Carriers (Alternative A)

Given this alternative, NLA is constructed with the capacity required to support traffic in the case that the current, network-carrier dominated traffic flows observed at Portela airport are maintained. This design is therefore best suited to Outcome 1, wherein the network carriers continue to determine Portuguese air transportation and continue to develop at today's rate of growth. Conversely, this alternative would falter given explosive growth of low-cost carriers and the decline of network carriers in Portugal. This is an artifact of terminal design; experiential data show that terminals designed primarily for the use of network carriers do not often prove optimum for attracting low-cost airlines. Therefore, if network carriers in Portugal falter, an airport built in this fashion may find it difficult to recover losses by seeking out greater LCC patronage.

Build Big for Low-Cost Carriers (Alternative B)

Alternative B presents the possibility of constructing NLA airport primarily to serve the LCC customer. The airport terminal would thus be best suited to accommodate the rapid growth of low-cost carriers accompanied by relatively small network carrier activity. Possible construction features would therefore include simple terminals with rapid-check in facilities (perhaps through decentralization), adequate but not ornate retail facilities, minimalist lounges, inexpensive surface access, and the spare capacity for rapid growth. Other features may include monetary support for promotional events, joint marketing, and a reduced emphasis on high-tech gate access. As a result, airport owners would likely experience significant cost savings in the construction of the terminal compared to Alternative A. Possible disadvantages to this alternative, however, would become apparent if the network carriers remained dominant (Outcome 2). In that case, NLA would likely find it difficult to attract the level of participation from network carriers that would be necessary to recover losses incurred during construction.

Build for Both LCC & NC (Alternative C)

In contrast to Alterative A and Alternative B, Alternative B suggests that designers construct the airport without assumption as to which outcome (LCC dominant or NC dominant) is most likely. Rather, airport designers could construct a smaller facility meant to accommodate either low-cost carriers or network carriers for a short period of time, effectively deferring the decision as to which group of air carriers would prove the most important in the future. Such a course, however, assumes that a degree of multi-functionality is constructed into the facility and that the airport planners ensure that the terminal could be expanded as need be in future.

System Development: Period II

Period II: How rapidly will NLA's air traffic develop over the next 15 years?

In Period II, which lasts from Year 10 to Year 25 of airport operation, the main cause of concern for airport operators is the development of traffic at the New Lisbon International Airport. This development may depend on several external factors, including the economic development of Portugal and the Lisbon region relative to other areas worldwide, trends in fuel prices, the development of competing transportation modes such as road and rail, and the preference for face-to-face rather than internet communication for business transactions. More locally, the ability of the Portuguese government to close Portela and to transfer its traffic to the new airport – a task which has proven difficult in several similar situations worldwide – could also have a significant impact on the long term growth rate NLA.

This aggregation of different chance outcomes highlights a strength of decision trees relative to binomial lattice models. Whereas the development of a binomial lattice requires assumptions regarding the growth rate of traffic over the total lifetime of the airport, the decision tree model can accommodate step changes in that growth rate resulting from a series of unpredictable factors. As a result, users operating the New Airport Terminal Model may choose to replicate the effect of any combination of events on traffic growth.

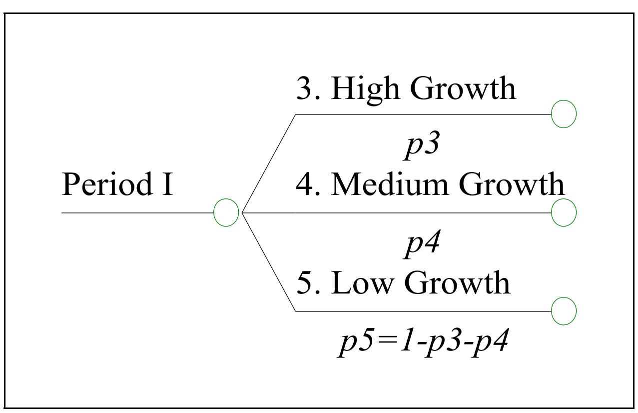


Figure A-18: Period II Chance Outcomes

For the purposes of the Lisbon Airport Scenario, the plausible growth rates at the New Lisbon International Airport have been aggregated to represent high growth, which occurs with probability *p3*, medium growth (*p4*), and low growth (*p5*) in Figure A-18.

Table A-3: Description of Period II Chance Outcomes

Chance Event	Description
4. High Growth	1. Exceptional economic development in Portugal 2. NLA develops to become a major regional airport
5. Medium Growth	1. Baseline economic development in Portugal 2. NLA growth rates slightly below trends at Portela
6. Low Growth	1. Low economic development in Portugal/Europe 2. Traffic slow to develop at NLA

Construction Alternatives

As in Period I, the New Airport Terminal Model allows the user to replicate construction alternatives at the beginning of Period II. However, in this case, capacity changes are more limited; the user only has two alternatives from which to choose. Of course, the Terminal Model assumes that these alternatives correlate with attempts to handle uncertainties surrounding traffic growth (low, medium, or high growth) in Period II. In order to add additional flexibility, however, the Terminal Model will accept different capacity alternatives depending on the outcome of Period I. For instance, in the case of the Lisbon Airport Scenario – in which either LCC or NC may dominate in Period I – the Terminal Model will allow the user different build choices for LCC-dominant and NC-dominant scenarios. Given that LCC are dominant, the Model assumes that the airport operator expands in order to serve the LCC customer; otherwise, the Model assumes that the operator expands in order to serve the network carriers.

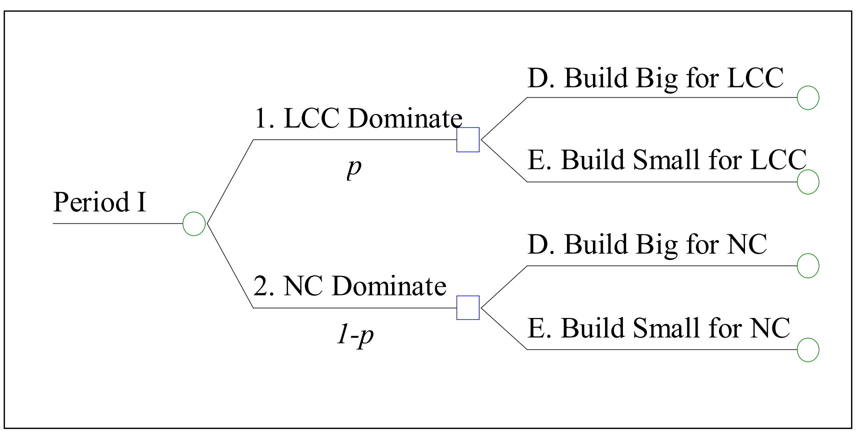


Figure A-19: Period II Alternatives

The Lisbon Airport Scenario in Chapter 5, for instance, presumes that airport operators either opt for large or small expansions to the airport terminal facilities. Figure A-19 illustrates the shape of a section of the decision tree after Period I assuming this setup.

Table A-4: Description of Period II Alternatives

Alternative Name	Description
D. Build Big	1. Major increase in the size of the facility 2. Assumes increase primarily serves the dominant traffic type (LCC or NC)
E. Build Small	1. Minor increase in the size of the facility 2. Assumes increase primarily serves the dominant traffic type (LCC or NC)

Build Big

Within the context of the Lisbon Airport Scenario, the Build Big alternative corresponds to a large increase in capacity. The capacity increase can serve multiple purposes. For instance, choosing to support a large capacity increase can correct for under-development (or incorrect development) in Period I or simply prepare the airport facility for positive traffic forecasts. In the case of the latter, Build Big should serve the airport best given high rates of traffic growth. However, it will likely result in waste if the rate of traffic growth is either low or negative.

Build Small

Referring again to the Lisbon Airport Scenario, the Build Small choice is best suited to situations in which the current airport capacity is sufficient for the current and forecast levels of traffic. If the capacity developed in Period I is insufficient or if passenger demand is expected to outstrip airport capacity however, building small would force the airport to surrender an opportunity for increased size, importance, and profit.

Period II Growth Rate and Correlation with Period I

In order to better replicate conditions within the air transport industry, the New Airport Terminal Model allows the user to enter Period II growth rates which differ depending on the outcome of Period I. The Lisbon Airport Scenario, which considers the possibility that LCC may come to dominate the European domestic market, encounters the necessity of this flexibility. A great deal of research within Europe shows that low-cost carriers are growing at rates far outstripping their legacy counterparts. Therefore, an LCC dominant air transport market may well grow at a different rate than an NC dominant market.

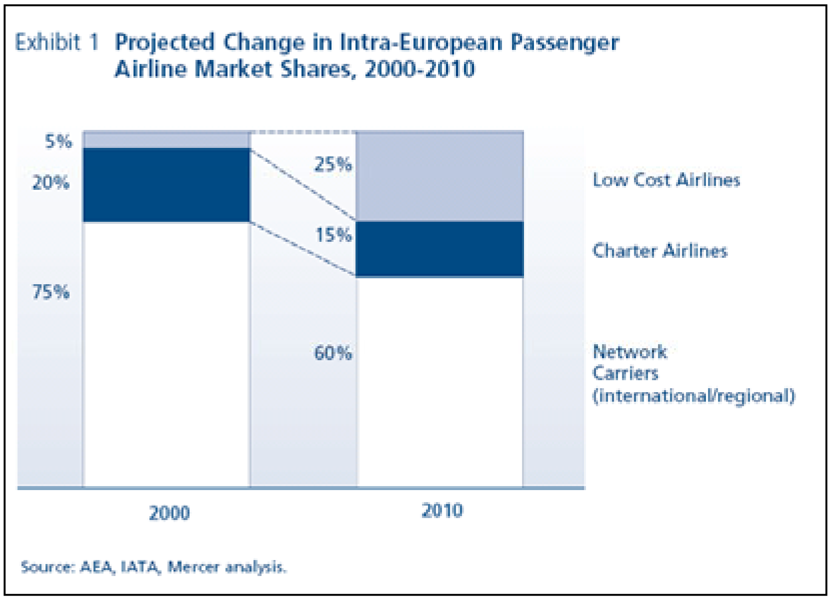


Figure A-20: LCC growth rates surpass those of NC (Mercer, 2002)

System Development: Full Decision Tree

The following figures present the full New Airport Terminal Model decision tree as designed for the Lisbon Airport Scenario.

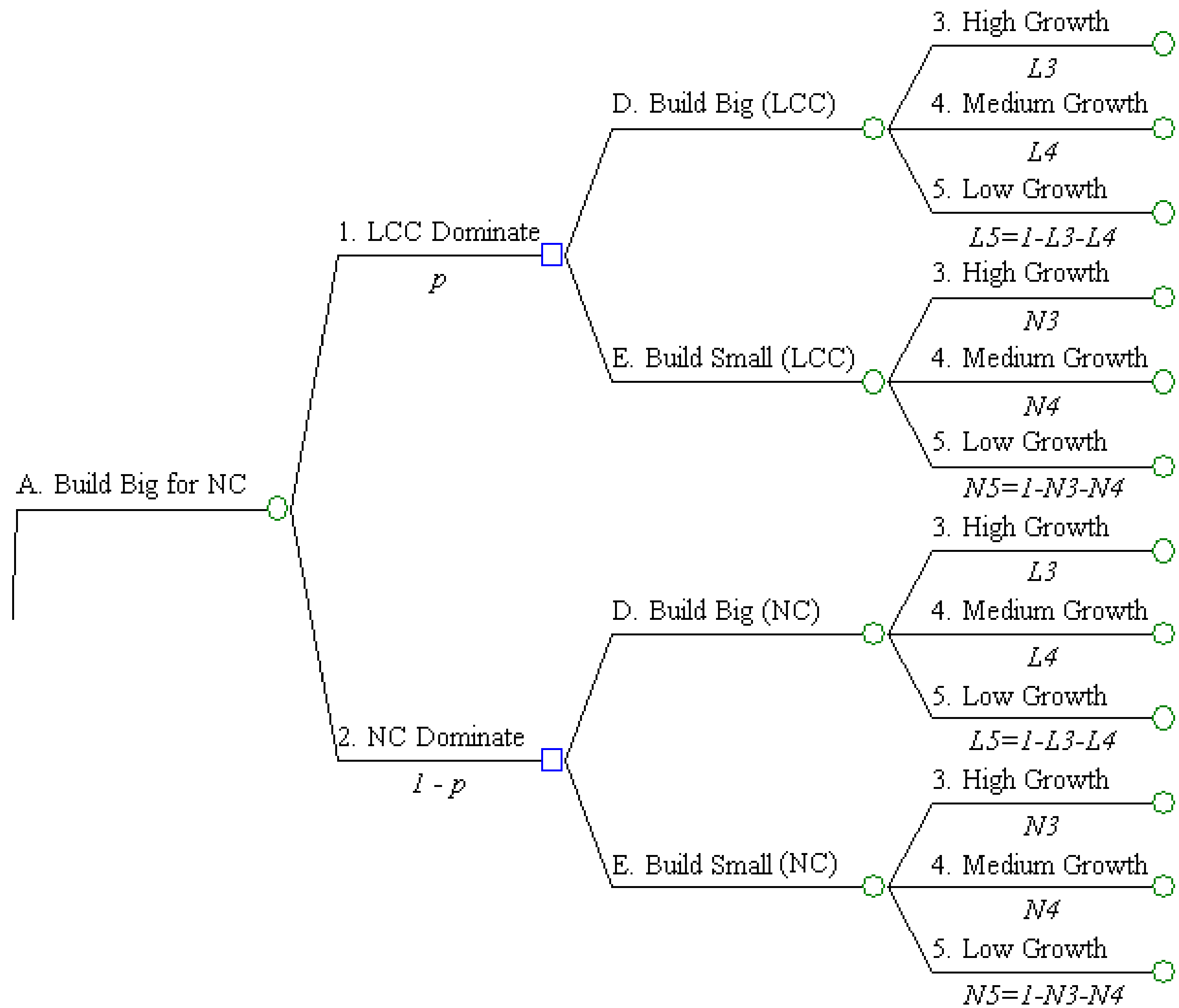


Figure A-21: Decision Tree | Build Big for Network Carriers

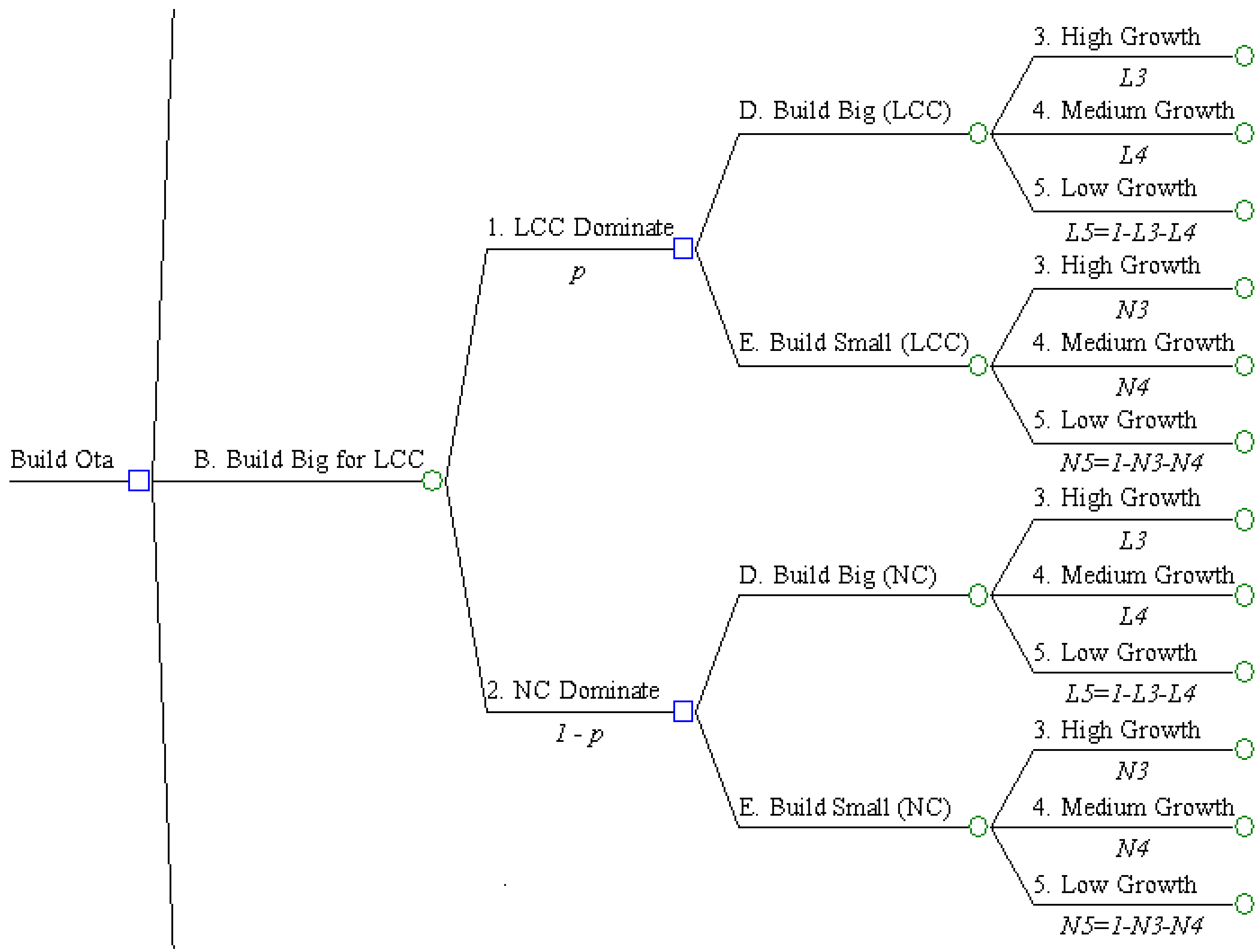


Figure A-22: Decision Tree | Build Big for Low-Cost Carriers

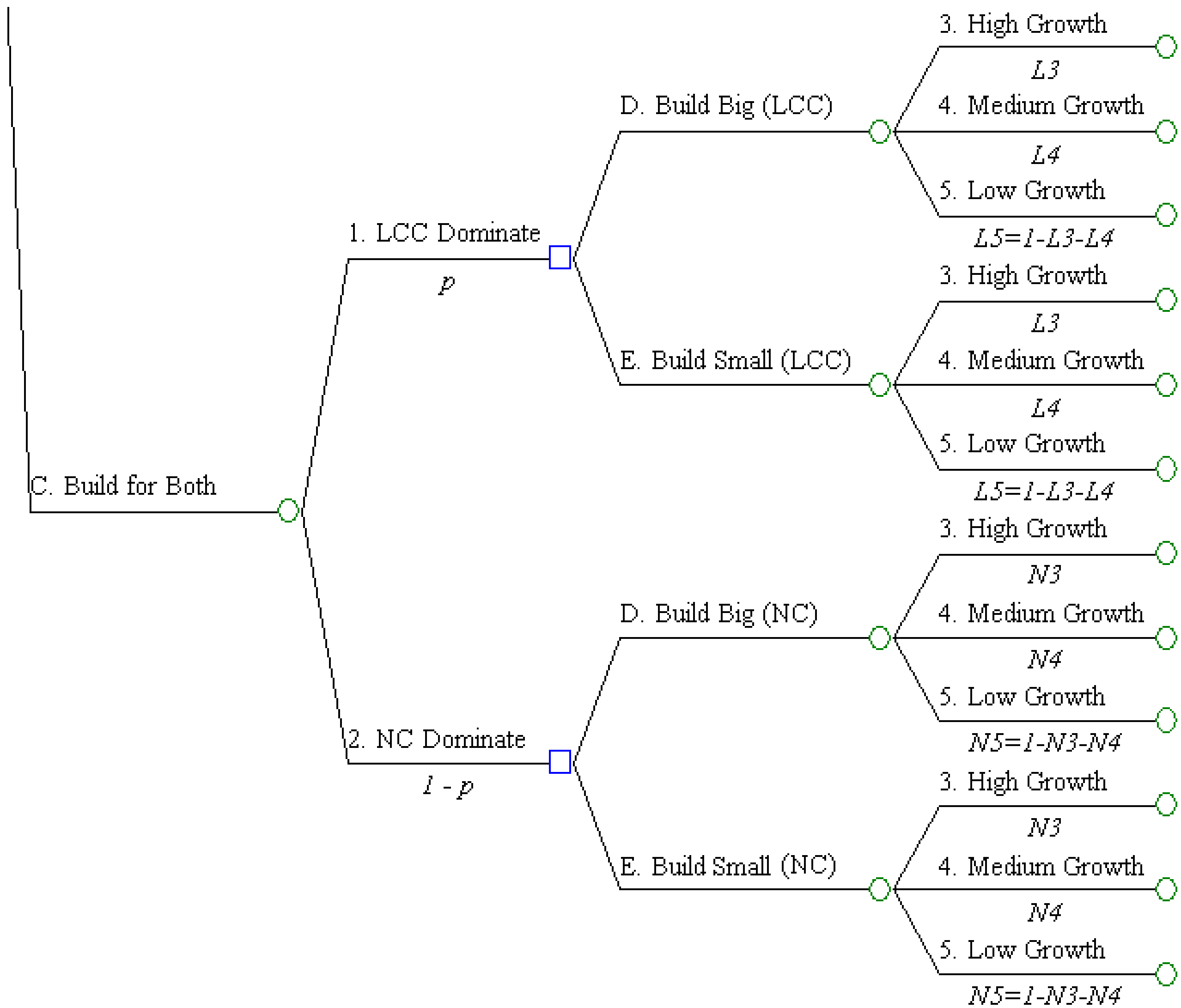


Figure A-23: Decision Tree | Build For Both

A4. The New Airport Terminal Model: Inputs and Instructions for use

The New Airport Terminal Model requires several simple inputs in order to determine which decision path maximizes the net present value of the airport being considered within a twenty-five year period. This section details what inputs are required and where they may be toggled in the Terminal Model. As such, this section is meant to serve as a guide to users wishing to conduct further sample runs. Further, the section also describes default inputs; these defaults were used in the Lisbon Airport Scenario unless otherwise stated.

<u>Entries Form A</u>

Entries Form A, the first tab in the Microsoft Excel© driven terminal decision tree model, accepts user inputs as to the probability of the various chance events accounted for by the model.

Period I Probabilities

PERIOD I: THE FIRST 10 YEARS

	Event		Assumed Probability	Default Value
1	LCC dominant	*P* =	65.00%	65.00%
2	NC dominant	*(1-P)* =	35.00%	35.00%

Discount Rate	0.12

Figure A-24: New Airport Terminal Model - Default Period I Probabilities

The New Airport Terminal Model's default values assume that low-cost carriers will come to dominate the European aviation industry (within the first few years after the airport's opening) with a 65% probability. This value has been selected in order to pay service to several predictions of ongoing LCC growth; it is not, however, assumed to be a definitively correct assumption.

A discount rate of 12%, which is common to government projects, is used.

Period II Probabilities

PERIOD II: THE REMAINING 15 YEARS

LCC Dominant

Given Decision: Build Big (D), LCC Dominant (1)			
Event		**Assumed Probability**	**Default Value**
3 High Growth	*LD3* =	35.00%	35.00%
4 Med. Growth	*LD4* =	50.00%	50.00%
5 Low Growth	*LD5* =	15.00%	15.00%
	Total	100%	100%

Given Decision: Build Small (E), LCC Dominant (1)			
Event		**Assumed Probability**	**Default Value**
3 High Growth	*LE3* =	35.00%	35.00%
4 Med Growth	*LE4* =	50.00%	50.00%
5 Low Growth	*LE5* =	15.00%	15.00%
	Total	100%	100%

Figure A-25: New Airport Terminal Model - Default Period II Probabilities | LCC Dominant

NC Dominant

Given Decision: Build Big (D), NC Dominant (2)			
Event		**Assumed Probability**	**Default Value**
3 High Growth	*ND3* =	15.00%	15.00%
4 Med. Growth	*ND4* =	50.00%	50.00%
5 Low Growth	*ND5* =	35.00%	35.00%
	Total	100%	100%

Given Decision: Build Small (E), NC Dominant (2)			
Event		**Assumed Probability**	**Default Value**
3 High Growth	*NE3* =	15.00%	15.00%
4 Med Growth	*NE4* =	50.00%	50.00%
5 Low Growth	*NE5* =	35.00%	35.00%
	Total	100%	100%

Figure A-26: New Airport Terminal Model – Default Period II Probabilities | NC Dominant

Default probabilities for high, medium, and low growth over Period II are assumed in the absence of detailed market data. As Figures A-25 and A-26 illustrate, medium growth patterns are the most likely. Further, the probability of high, medium, or low growth, though affected by events in Period I (what type of traffic is most important at the airport), has no dependence and by decisions on how to build in Period II.

The Lisbon Airport Scenario deviates from the default values already shown. Rather, the input values used are modified in an attempt to represent experiential data garnered from across Europe. Sample airports such as Frankfurt-Hahn (HHN) have borne out a simple principle: traffic development at new airports will likely not prove independent of decisions on how to build the airport (especially for LCC customers), as the Terminal Model presumes in Period I. Rather, the decision to cater specifically to low-cost carriers does help determine the probability of rapid traffic growth due to the entrance of players such as Ryanair or easyJet, a phenomenon which could be repeated at new airports in Portugal. Further, research suggests that LCC prefer serving airports with the additional capacity required to support rapid expansion; those airports are therefore more likely to benefit from the high-growth rates often accompanying LCC patronage (Barrett, 2004).

Being cognizant of this dynamic, the Lisbon Airport Scenario's input values reflect some dependence both on the type of traffic which has come to dominate and on how much free capacity is provided for expansion. Therefore, airports with larger capacities are more likely to attract new airlines and their associated traffic. This effect is more pronounced with low-cost carriers, as research suggests that spare capacity is a top priority for these airlines (Warnock-Smith, 2005).

LCC Dominant

Given Decision: Build Big (D), LCC Dominant (1)

Event		Assumed Probability	Default Value
3 High Growth	*LD3* =	40.00%	35.00%
4 Med. Growth	*LD4* =	60.00%	50.00%
5 Low Growth	*LD5* =	0.00%	15.00%
	Total	100%	100%

Given Decision: Build Small (E), LCC Dominant (1)

Event		Assumed Probability	Default Value
3 High Growth	*LE3* =	20.00%	35.00%
4 Med Growth	*LE4* =	45.00%	50.00%
5 Low Growth	*LE5* =	35.00%	15.00%
	Total	100%	100%

NC Dominant

Given Decision: Build Big (D), NC Dominant (2)

Event		Assumed Probability	Default Value
3 High Growth	*ND3* =	23.00%	15.00%
4 Med. Growth	*ND4* =	57.00%	50.00%
5 Low Growth	*ND5* =	20.00%	35.00%
	Total	100%	100%

Given Decision: Build Small (E), NC Dominant (2)

Event		Assumed Probability	Default Value
3 High Growth	*NE3* =	10.00%	15.00%
4 Med Growth	*NE4* =	45.00%	50.00%
5 Low Growth	*NE5* =	45.00%	35.00%
	Total	100%	100%

Figure A-27: Lisbon Airport Scenario - Period II Probability Values

Entries Form B

Airport Capacity

Entries Form B, the second tab in the Microsoft Excel© workbook, allows the user to change the size of each airport construction alternative in terms of passengers served per year. Demand is generally assumed to be divided into two non-overlapping categories. This is a simplification; in certain cases, passenger types can and do overlap (with domestic and international travelers being a notable exception). However, the assumption of separation should prove suitable for preliminary analyses.

The input form accepts data regarding construction for Period I under the heading "Initial Capacities (people)". Non-positive capacities yield erroneous results. Inputs regarding construction for Period II are accepted under the heading "Capacity Increases (people)". Here, negative values carry a specific meaning regarding the switching of spaces.

Capacities								
Initial Capacities (people)						Capacity Increases (people)		
Decision	LCC	NC					LCC	NC
A. Big NC	2,000,000	15,000,000	A		D	Build Big(LCC)	20,000,000	1,000,000
B. Big LCC	28,000,000	2,000,000	B		D	Build Big(NC)	1,000,000	14,000,000
C. Small Ota	5,000,000	3,000,000	C		E	Build Small (LCC)	0	0
					E	Build Small (NC)	0	0

Figure A-28: New Airport Terminal Model - Default Construction Alternatives

Within the context of the Lisbon Airport Scenario, the separate demand types are low-cost and network carrier passengers. As a result of the non-overlap assumption, these passenger groups are modeled as being entirely exclusive. As such, capacity designed to service low-cost carriers cannot service passengers flying on low-cost airlines. The converse is also true: passengers on network carriers cannot be accommodated with facilities for low-cost carriers. Although this separation is not necessary, research has noted that both low-cost airlines and low-cost passengers tend to desire different services from their terminals.

Capacities								
Initial Capacities (people)						Capacity Increases (people)		
Decision	LCC	NC					LCC	NC
A. Big NC	2,000,000	15,000,000	A		D	Build Big(LCC)	0	-5,000,000
B. Big LCC	28,000,000	2,000,000	B		D	Build Big(NC)	-5,000,000	0
C. Small Ota	5,000,000	3,000,000	C		E	Build Small (LCC)	0	0
					E	Build Small (NC)	0	0

Figure A-29: New Airport Terminal Model - Sample Capacity Inputs with Switching

Referring back to the concept of switching terminal spaces from one use to another, a negative value in the square highlighted in Figure A-29, for instance, means the following:

- Build Big (LCC) – LCC proved dominant in Period I

- Build Big (LCC) – The model will consider this a large capacity increase and use the associated probabilities. This has no effect given default values.

- -5,000,000 – The capacity for 5 million people will be switched from the NC use to the LCC carrier.

It should be noted that the default values used in the thesis' Lisbon Airport Scenario result from forecasts internally generated by the model.

Traffic Development

Growth Rates & Demand | Chance Event										
Period I: The First 10 years										
	Chance Event	LCC Demand	NC Demand	LCC Growth	NC Growth					
	1. LCC dom.	200,000	200,000	50.00%	20.00%					
	2. NC dom.	200,000	200,000	20.00%	40.00%					
Period II: The Next 15 Years										
Given LCC Dominant						Given NC Dominant				
	LCC Growth	NC Growth					LCC Growth	NC Growth		
High Growth	12.00%	8.00%	3	3	High Growth	8.00%	12.00%			
Med. Growth	9.00%	6.00%	4	4	Med. Growth	6.00%	9.00%			
Low Growth	5.00%	4.00%	5	5	Low Growth	4.00%	5.00%			

Figure A-30: New Airport Terminal Model - Default Growth Rates

Model users further have the ability to define initial traffic levels as well as growth rates for different customer types. In order for the model to function, initial demand levels must be positive and non-zero. Default values provide for an arbitrarily selected 200,000 passengers a year in each of the two non-overlapping categories; this input provides a lower bound for airport traffic, barring negative growth rates[17]. The Lisbon Airport Scenario uses slightly higher base demand, at 275,000 per category. This value allows for the expected value of passenger traffic at Year 22 to match actual predictions for the New Lisbon International Airport.

Default growth rates derive from various sources. Period I growth in low-cost and network carrier growth in Period I, for instance, loosely mirror events at the relatively new facilities at Frankfurt-Hahn and Hong Kong International (HKG), respectively. These values are slightly below the current experience at Lisbon Portela Airport. However, given the volatility of new airports in multi-airport systems, this reduction in average growth is not unlikely. Indeed, it may well be generous. Period II growth rates, on the other hand, derive from data available on Frankfurt-Hahn and Denver International Airport (DIA); medium growth rates roughly mirror nominal industry growth as provided by Eurocontrol (Aguado, 2006).

[17] Users wishing to employ negative growth rates must be cautious; the Terminal Model is not designed to screen out negative passenger levels which may result from negative growth.

Airport Revenues

Costs & Revenues						
	LCC	NC			LCC	NC
Capital Cost/M2	1600	2000		Revenue/Pax	$16	$20
Maintenance Cost/Person	3	3				

Figure A-31: New Airport Terminal Model - Default Revenue Structure

The Model determines costs and revenues based on the size of capacity increments and the development of traffic as described by the user inputs.

Revenue calculations rely on user estimates as to the average revenue obtained per customer. Different values may be assumed for LCC and NC passengers, as low-cost customers and airlines tend to pay significantly less in airport fees than their network carrier counterparts. Average revenue per passenger values derive from Munich Franz Josef Strauss International (MUC) and Frankfurt Hahn (HHN) airports for NC and LCC passengers, respectively.

Airport costs, meanwhile, are determined using a simple computation, as described in Equation A-7. Average capital costs for network carriers and low-cost carriers come from various sources while average maintenance costs per person are available from the World Bank (Gannon, 1995). Although there is evidence to suggest that low-cost terminals enjoy lower maintenance costs, no data was available on the savings; therefore, this phenomenon remains unaccounted for in the Terminal Model. For calculation purposes, the Terminal Model assumes that maintenance costs are paid on a yearly basis at the beginning of the year; capital costs are paid out over the period currently being examined (Period I or Period II) in equal increments. All costs and revenues are discounted to net present values in the final value calculations.

Equation A-7: Airport Costs

$$\text{Total Capital Cost} = \left(\text{Capital Cost/m}^2\right) * \text{Airport Size}$$
$$\text{Total Maintenance Cost} = \left(\text{Maintenance Cost/Person}\right) * \text{Passengers\_Served}$$

Airport Sizing

Service Standards					
Average Hour Conversion Factor				Peak Hour Conversion Factor	0.0007
	LCC	NC		Dwell Time (minutes)	120.0000
Design Service Standard	25	30	m2/person	*Design standard reflects m2/peakhour passenger*	

Figure A-32: New Airport Terminal Model - Default Service Standards

Given information on how many passengers designers wish to serve, the New Airport Terminal Model independently determines the size of the facilities required as a function of desired passenger capacity, design service standards for the network and low-cost carriers, and average dwell time. Each of these values must be input by the user. Default values, however, were determined using data from London Heathrow Airport (LHR) and other experiential data.

In airport planning, the peak capacity of an airport is usually estimated using a series of conversion factors in order to calculate peak capacity based on the busiest day of the year. This information is simply unavailable for new airports like New Lisbon International, as the airport has not yet opened. Therefore, the model accepts a single input, the peak hour conversion factor, to convert the total desired passenger capacity into an estimate of peak traffic. The size of the terminal (m2) required is thus determined as in Equation A-8.

Equation A-8: Calculating Airport Size

$$\boxed{\begin{array}{l}\text{Terminal Size } (m^2) = \text{Peak Hour Passengers} * \text{Dwell Time} * \text{Design Service Standard} \\ \text{Peak Hour Passengers} = \text{Peak Capacity} * \text{Peak Hour Conversion Factor}\end{array}}$$

As per normal airport planning techniques, the terminal is sized to fit the number of passengers in the building at any particular moment during the year's busiest hour. Each passenger is then assigned a certain amount of space, the design service standard.

Forecasts Tab

Although real options thinking generally condones a reduced dependence on forecasting, it is quite clear that forecasts must remain an important part of the airport planning process. In light of this, the New Airport Terminal Model internally produces forecasts and presents them in their own tab; these numbers are intended to help the user appropriately size construction projects at the beginning of Periods I and II.

The forecasting methodology is simple. The Model assumes that, given an initial passenger demand, the growth rate during each Period remains constant. Equation A-9 provides a sample calculation using the default values as highlighted in Figure A-33.

Growth Rates & Demand | Chance Event					
Period I: The First 10 years					
	Chance Event	LCC Demand	NC Demand	LCC Growth	NC Growth
	1. LCC dom.	200,000	200,000	50.00%	20.00%
	2. NC dom.	200,000	200,000	20.00%	40.00%

Period II: The Next 15 Years

Given LCC Dominant	LCC Growth	NC Growth			Given NC Dominant	LCC Growth	NC Growth
High Growth	12.00%	8.00%	3	3	High Growth	8.00%	12.00%
Med. Growth	9.00%	6.00%	4	4	Med. Growth	6.00%	9.00%
Low Growth	5.00%	4.00%	5	5	Low Growth	4.00%	5.00%

Figure A-33: New Airport Terminal Model - Forecasting Sample Inputs

Equation A-9: Terminal Model – Sample Forecasting Result

$$\text{NC Demand (Yr 10)} = \text{NC Demand (Yr 0)} * (1 + \text{NC Growth Rate (Yr 0)})^{9}$$

$$\text{NC Demand (Yr 25 | NC Dominant)} = \text{NC Demand (Yr 10)} * (1 + \text{NC Growth Rate (Yr 10)})^{14}$$

$$\text{NC Demand (Yr 10)} = 200{,}000 * (1 + .4)^{9}$$

$$\text{NC Demand (Yr 10)} = 4{,}132{,}209 \approx 4 \text{ million passengers}$$

$$\text{NC Demand (Yr 25 | NC Dominant)} = 4{,}132{,}209 * (1 + .12))^{14}$$

$$\text{NC Demand (Yr 25)} = 22{,}617{,}920 \approx 23 \text{ million passengers}$$

	Period I Forecasts: Traffic at Yr 10			
Chance Event		**LCC**	**NC**	
	LCC Dominant	7,689	1,032	[kpax]
	NC Dominant	1,032	4,132	[kpax]
	--	--	--	[kpax]

LCC Dominant

	Period II Forecasts: Traffic at Yr 25			
Chance Event		**LCC**	**NC**	
	High Growth	42,084	3,274	[kpax]
	Medium Growth	28,006	2,473	[kpax]
	Low Growth	15,984	1,858	[kpax]

NC Dominant

	Period II Forecasts: Traffic at Yr 25			
Chance Event		**LCC**	**NC**	
	High Growth	3,274	22,618	[kpax]
	Medium Growth	2,473	15,052	[kpax]
	Low Growth	1,858	8,591	[kpax]

Figure A-34: New Airport Terminal Model - Sample Forecasts

Lisbon Airport Scenario Forecasts

Forecasts in the Lisbon Airport Scenario differ from those in the Terminal Model's default state due to higher initial demand inputs. Figure A-35 illustrates. The user may note that the expected value of passenger traffic in Year 22 (2039, assuming that NLA opens in 2017) is approximately 33 million passengers assuming that no additional construction occurs in Period II (Build Small). This is meant to match current NLA forecasts (BPCC, 2007).

SIMPLE FORECASTS

Chance Event	Period I Forecasts: Traffic at Yr 10			
		LCC	NC	
	LCC Dominant	10,572	1,419	[kpax]
	NC Dominant	1,419	5,682	[kpax]
	--	--	--	[kpax]

LCC Dominant

Chance Event	Period II Forecasts: Traffic at Yr 25			
		LCC	NC	
	High Growth	57,866	4,501	[kpax]
	Medium Growth	38,508	3,401	[kpax]
	Low Growth	21,978	2,555	[kpax]

NC Dominant

Chance Event	Period II Forecasts: Traffic at Yr 25			
		LCC	NC	
	High Growth	4,501	31,100	[kpax]
	Medium Growth	3,401	20,696	[kpax]
	Low Growth	2,555	11,812	[kpax]

FORECAST CHECK

Build Big	Forecast Check: E (Yr 22 Demand)			
	Chance Events	Traffic [kpax]	Probability	E(Demand) [kpax]
	1,3	62,367	26.00%	16,215
	1,4	41,909	39.00%	16,344
	1,5	24,534	0.00%	0
	2,3	35,601	8.05%	2,866
	2,4	24,096	19.95%	4,807
	2,5	14,367	7.00%	1,006
		Totals	**1**	**41,238,654**

Build Small	Forecast Check: E (Yr 22 Demand)			
	Chance Events	Traffic [kpax]	Probability	E(Demand) [kpax]
	1,3	62,367	13.00%	8,108
	1,4	41,909	29.25%	12,258
	1,5	24,534	22.75%	5,581
	2,3	35,601	3.50%	1,246
	2,4	24,096	15.75%	3,795
	2,5	14,367	15.75%	2,263
		Totals	**1**	**33,251,510**

Figure A-35: Lisbon Airport Scenario - Forecasts

Calculator Tab

The Calculator Tab calculates the net present value (NPV) of decisions in Period I only. The user can toggle which construction alternative is being considered by editing the number and letter values in the highlighted cells. Changing the values in these cells will cause the Calculator tab to show calculations distinct to that combination of Period I construction choice and chance event. Table A-5 and Figure A-36 remind the user which letters and numbers correspond to Period I decisions and events in the Lisbon Airport Scenario. Changing the values in the highlighted cells has no bearing on the operation of the New Airport Terminal Model; rather, this functionality is designed only to allow the user to explore individual scenarios in detail.

PERIOD I: THE FIRST 10 YEARS

Alternative	B	Insert A - C
Chance Event	2	Insert 1 - 2

	LCC	NC	
Initial Capacity	28,000,000	2,000,000	pax
Initial Demand	200,000	200,000	pax
Growth Rate	0.2	0.4	pax/yr

Figure A-36: New Airport Terminal Model – Sample Period I Calculator Tab Inputs

Table A-5: New Airport Terminal Model - Period I Calculator Tab Inputs

Alternatives		Chance Outcomes	
A	Build Big for NC	**1**	LCC Dominant
B	Build Big for LCC	**2**	NC Dominant
C	Build for Both		

For the convenience of the user, the Calculator tab presents independent computations broken down by passenger type. For the Model default state, this represents LCC and NC customers. Figure A-36 shows the calculations for the first three of ten years in Period I. The first group of rows presents information on the available LCC capacity in terms of passengers served and actual physical size of LCC terminal facilities. The second group of rows gives the actual LCC passenger demand and passengers served. The number of passengers served is bounded by the actual capacity of the facility. Rows thereafter describe airport revenue streams per year. Terminal capital costs are paid in equal increments starting in Year 0, the year before the airport begins serving customers. Finally, the net-present value of the facility is provided per customer type.

LCC Capacity and Revenue Development				
Year	0	1	2	3
LCC Capacities (thousands)				
LCC Capacity (people)	28,000	28,000	28,000	28,000
LCC Capacity (size)	933	933	933	933
LCC Demand (kpeople)				
LCC Demand	--	200	240	288
LCC Served		200	240	288
LCC Costs/Income (k$)				
LCC Capital Costs	$135,758	$135,758	$135,758	$135,758
LCC Ops/Maintenance		$600	$720	$864
LCC Income		$3,200	$3,840	$4,608
LCC Cashflow (k$)				
LCC Cashflow	$135,758	$133,158	$132,638	$132,014
LCC Discounted Cashflow (k$)				
Overall DCF (LCC Costs)	$135,758	$121,748	$108,799	$97,245
Overall DCF (LCC Total)	$135,758	$118,891	$105,738	$93,965
NPV(LCC Costs) | Period 1 [k$]	$910,270			
NPV(LCC Cashflow) | Period 1 [k$]	$870,527			

Figure A-37: New Airport Terminal Model - Example Calculator Tab

Aggregated data for the entire facility as constructed in Period I is presented in a series of Microsoft Excel© data tables at the bottom of the tab, as demonstrated in Figure A-37. The overall cost shown provides a summation of capital and maintenance costs. This result, of course, depends on a combination of the decisions and chance events in Period I. According to the figure, for instance, if planners build an airport designed for NC but LCC come to dominate the market (A1, as highlighted for reader ease), airport costs come to US $814 million. Total cash-flow, which includes income from passenger fees, however is US $675 million.

Overall Results				
NPV(Overall Costs) | Period 1 [k$]		Alternatives		
		A	B	C
	1	$814,183	$1,034,737	$338,769
	2	$815,232	$1,021,594	$330,486
NPV(Overall Cashflow) | Period 1 [k$]		Alternatives		
		A	B	C
	1	$675,087	$837,129	$155,737
	2	$656,728	$884,559	$179,273
E(NPV_Overall_Cashflow) | Period 1 [k$]				
		A	B	C
	E(NPV) [k$]	$668,662	$853,730	$163,975

Figure A-38: New Airport Terminal Model - Sample Period I Calculator Results

Finally, the Calculator tab shows the New Airport Terminal Model's calculation of the expected value of each construction decision given Period I only. This value is the sum of the products of the probabilities of each chance event and their corresponding net present value. The expected net present value of building for NC (A), then, is as presented in Equation A-10, using default values in the New Airport Terminal Model.

Equation A-10: New Airport Terminal Model - Sample Period I Computation

$$
\begin{aligned}
&E(NPV \mid A) = Pr(1) * Cashflow(A1) + Pr(2) * Cashflow(A2) \\
&E(NPV \mid A) = 65\% * (\text{-\$675 million}) + 35\% * (\text{-\$657 million}) \\
&E(NPV \mid A) = -\$669 \text{ million}
\end{aligned}
$$

Calculator2 Tabs

The remaining Calculator tabs calculate the net present values for each available alternative in Period II. These net present values represent the total value of the airport in 25 years. As before, the user can toggle which construction alternative is presented on the screen by editing the values in the highlighted cells. Table A-6 recaps the combinations as used in the Lisbon Airport Scenario.

Table A-6: New Airport Terminal Model - Period II Calculator Tab Inputs

Alternatives		**Chance Outcomes**	
D	Build Big (LCC or NC)	**1**	High Growth
E	Build Small (LCC or NC)	**2**	Medium Growth
		3	Low Growth

Six different Calculator tabs provide the data required for Period II with each one corresponding to a particular combination of decisions and chance events in Period I: they are Calculator2 (A1), Calculator2 (A2), Calculator2 (B1), Calculator2 (B2), Calculator2 (C1), and Calculator2 (C2). Each performs the same function of calculating expected net present values of net income. However, each tab is keyed to its own combination of Period I occurrences. Therefore, all information regarding Period II, assuming that the original airport structure was constructed to LCC standards and LCC came to dominate the passenger market is presented under tab Calculator2 (B1).

PERIOD II: THE REMAINING 15 YEARS

Alternative	D	Insert D - E
Chance Event	3	Insert 3 - 5

Inputs from Period I

	LCC	NC	
Yr 10 Capacity	02,000	15,000	kpax
Yr 10 Size	66,667	600,000	m2
Yr 10 Demand	07,689	01,032	kpax
Yr 10 Growth Rate	50.00%	20.00%	pax/yr

Yr 10 NPV(Costs)	$814,183	k$
Yr 10 NPV(Total)	$675,087	k$

Updated Values for Period II

	LCC	NC	
New Built Capacity (Year 11)	20,000	01,000	kpax
New Built Size (Year 11)	666,667	40,000	m2
Switched Capacity from LCC (Year 11)	0	0	kpax
Switched Capacity from NC (Year 11)	0	0	kpax
New Total Capacity (Yr 11)	22,000	16,000	kpax
New Size (Yr 11)	733,333	640,000	m2
New Growth Rate	0.12	0.08	pax/yr

Figure A-39: New Airport Terminal Model – Sample Period II Calculator Tab Inputs

Period II revenues are calculated in exactly the same manner as in Period I. Revenue summaries are presented in a series of data tables at the bottom of the page. Figure A-39 presents sample results from Calculator2 (A1), which assumes that the original terminal was built to service NC traffic but LCC carriers proved dominant (A1). In this case, highlighted cells represent results given that airport managers choose to build large structures in Period II and a high rate of traffic growth comes to pass (D3).

Overall Results					
NPV(Overall Cashflow) | Period 2 only [k$]		D		E	
		3	$263,679		$121,139
		4	$255,653		$113,113
		5	$248,825		$106,285
NPV(Overall Costs) | 2 Periods [k$]	871,550,582	D		E	
		3	$871,551		$838,657
		4	$870,134		$837,241
		5	$868,929		$836,036
NPV(Overall Cashflow) | 2 Periods [k$]	411,408,677	D		E	
		3	$411,409		$553,948
		4	$419,434		$561,974
		5	$426,262		$568,802
E(NPV_Overall_Cashflow) | 2 Periods [k$]		A1D		A1E	
	E(NPV)		$416,224		$562,759

Figure A-40: New Airport Terminal Model – Sample Period II Calculator2 Results

The expected value of overall cash-flow in Period II is calculated in the same manner as in Period I. Equation A-11 shows how the New Airport Terminal Model computes the expected value of building big for LCC given that (A1) occurred in Period I, given the probabilities used in the New Airport Model.

Equation A-11: New Airport Terminal Model – Sample Period II Computation

$$\begin{aligned}
&E(NPV \mid D) = Pr(3) * Cashflow(D3) + Pr(4) * Cashflow(D4) + Pr(5) * Cashflow(D5) \\
&E(NPV \mid D) = 40\% * (\text{-}\$\,411\text{ million}) + 60\% * (\text{-}\$\,419\text{ million}) + 0\% * (\text{-}\$\,426\text{ million}) \\
&E(NPV \mid D) = -\$416\text{ million}
\end{aligned}$$

<u>Results Tab</u>

The Results tab presents expected net present values associated with each decision alternative (A-E) and suggests the best decision path as determined by maximum net present value calculated over twenty-five years of airport operation. This process begins by collating data from other tabs and presenting them in a single, accessible format.

Results from Period I						
E(NPV)						
	A	B	C			
E(NPV) [k$]	$668,662	$853,730	$163,975			
Results from Period II						
	A1	A2	B1	B2	C1	C2
E(NPV) [k$]	$416,224	$365,978	$411,375	$616,699	$46,793	$58,114
Best Choice	D	E	E	D	D	D
Best Choice	Build Big	Build Small	Build Small	Build Big	Build Big	Build Big
	A		B		C	
E(NPV) [k$]	$398,638		$483,239		$50,755	
Gain in P2	*$270,024*		*$370,491*		*$214,730*	
Best Choice	C	$50,755	[k$]			
	In Period I,	**the best choice is to**	**Build for Both (C)**			

Figure A-41: New Airport Terminal Model - Sample Results Presentation

The final recommendation of the New Airport Terminal Model is presented at the bottom of the Results tab; this counsel provides guidance on how to build in Period I given the input values. The Model simply selects the Period I alternative with the greatest probability of positive financial returns (highest expected NPV) over the period of interest, twenty-five (25) years. The calculation of the expected value of each Period I alternative proceeds as described in Equation A-12 using information as highlighted in Figure A-41.

Equation A-12: New Airport Terminal Model - Sample Results Tab Calculation

$$\boxed{\begin{aligned} &\mathrm{E(NPV} \mid \mathrm{A}) = \Pr(1) * (\mathrm{E(NPV)} \mid \mathrm{A1}) + \Pr(2) * (\mathrm{E(NPV)} \mid \mathrm{A2}) \\ &\mathrm{E(NPV} \mid \mathrm{A}) = 65\% * (\text{-\$ 416 million}) + 35\% * (\text{- \$ 366 million}) \\ &\mathrm{E(NPV} \mid \mathrm{A}) = -\$399 \text{ million} \end{aligned}}$$

In addition, best choice recommendations are also presented for Period II. According to Figure A-41, for example, if A1 occurs, the Model suggests that managers “Build Big.” As per the setup of the Model, this large construction would serve the LCC customer. This counsel, however, should not be interpreted as final; this would remove the ability to defer decisions. Rather, given that airport managers have ten years to re-evaluate airport trends, it is quite likely that the Model should be run again with new data before such a decision is made. Such an evaluation concludes the use of New Airport Terminal Model for the particular case being modeled. Repeated analyses, however, can be used to present a fuller picture and to compare the effects of changing various sample inputs.

A5. The New Airport Terminal Model: Evaluating Real Options

The following sections describe the Terminal Model setup used to evaluate the possible benefits of real options thinking in airport planning. The New Airport Terminal Model default values were used with one exception; initial traffic is 250,000 passengers per customer type rather than 200,000.

Deferring Decisions

Two Strategies

Table A-7: Deferring Decisions Evaluation – Two Strategies

		Planners With Option	Planners Without Option
Period I	**Capacity Provided (pax)**	10 million	10 million
	Customer Served	LCC or NC	LCC or NC
Period II	**New Capacity (pax)**	10 million	10 million
	Customer Served	LCC or NC	NC

Model Set-up

Capacities							
Initial Capacities (people)					**Capacity Increases (people)**		
Decision	LCC	NC				LCC	NC
A. Big NC		10,000,000	A	D	Build Big(LCC)		10,000,000
B. Big LCC	10,000,000		B	D	Build Big(NC)		10,000,000
			C	E	Build Small (LCC)		10,000,000
				E	Build Small (NC)		10,000,000

Figure A-42: Deferring Decisions Evaluation – Strategy without Option

Capacities							
Initial Capacities (people)					**Capacity Increases (people)**		
Decision	LCC	NC				LCC	NC
A. Big NC		10,000,000	A	D	Build Big(LCC)	10,000,000	
B. Big LCC	10,000,000		B	D	Build Big(NC)		10,000,000
			C	E	Build Small (LCC)	10,000,000	
				E	Build Small (NC)		10,000,000

Figure A-43: Deferring Decisions Evaluation – Strategy with Option

(Note: In this scenario, airport planners must build additional capacity for 10 million annual passengers at the end of ten years. The Build Big and Build Small options are therefore not differentiable.)

Model Results & Option Value

Given default values, it is possible to determine the value of the deferral option[18] by running the model once for each strategy and comparing the expected financial results.

Table A-8: Deferring Decisions Evaluation – Result of Strategy without Option

	Build for NC (A)		Build for LCC (B)
E(NPV) [k$]	$361,404		$24,466
Gain in P2	*$43,775*		*$235,118*
Best Choice	B	$24,466 [k$]	

Given the hypothetical data in this scenario, the airport nets some US $24 million in present dollars. The picture, however, is much improved if planners are given the option to choose which customer to build for in Period II. In this case, the best possible choice – given the input data, building for LCC (B) – yields an expected profit of US $103 million in present dollars.

Table A-9: Deferring Decisions Evaluation – Result of Strategy with Option

	Build for NC (A)		Build for LCC (B)
E(NPV) [k$]	$150,762		$103,175
Gain in P2	*$254,417*		*$313,826*
Best Choice	B	$103,175 [k$]	

In this particular circumstance, then, the value of maintaining the flexibility to choose which customer to build for in Period II is worth US $79 million.

[18] This model assumes that buildings constructed for low-cost and network carriers are not interchangeable.

Value-at-Risk/Gain

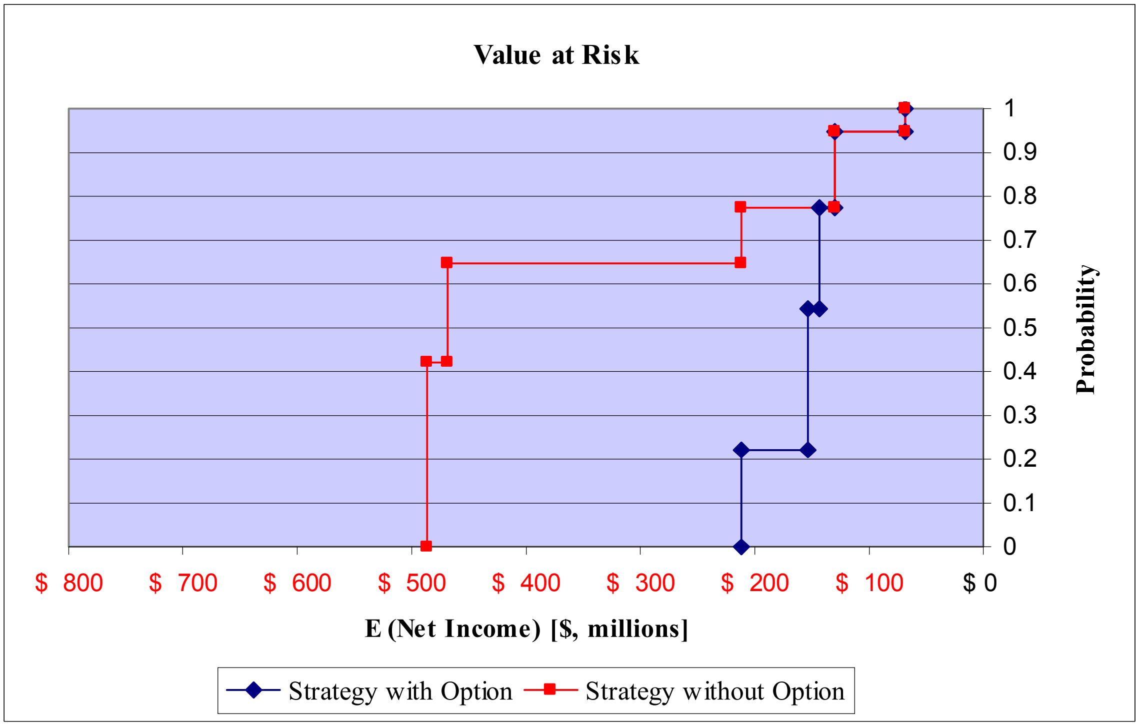


Figure A-44: New Airport Terminal Model – Deferring Decisions can reduce Downside Risk

<u>Multi-functionality: The Right to Switch</u>

Two Strategies

Table A-10: Deferring Decisions Evaluation – Two Strategies

		Planners With Option	**Planners Without Option**
Period I	**Capacity Provided (pax)**	10 million	10 million
	Customer Served	LCC or NC	LCC or NC
Period II	**New Capacity (pax)**	5 million switched or No change	No change
	Customers Served	LCC & NC	No change

Model Set-up

The model set-up is described in Figures A-45 and A-46. Negative capacity increases indicate that capacity has been switched from serving one customer to another.

Capacities							
Initial Capacities (people)					Capacity Increases (people)		
Decision	LCC	NC				LCC	NC
A. Big NC	0	10,000,000	A	D	Switch (LCC)	0	0
B. Big LCC	10,000,000	0	B	D	Switch (NC)	0	0
			C	E	No Change	0	0
				E	No Change	0	0

Figure A-45: Multi-functionality Evaluation – Strategy without Option

Capacities							
Initial Capacities (people)					Capacity Increases (people)		
Decision	LCC	NC				LCC	NC
A. Big NC	0	10,000,000	A	D	Switch (LCC)	0	-5,000,000
B. Big LCC	10,000,000	0	B	D	Switch (NC)	-5,000,000	0
			C	E	No Change	0	0
				E	No Change	0	0

Figure A-46: Multi-functionality Evaluation – Strategy with Option

Model Results & Option Value

Actually valuing the option to switch requires one additional step. In order to do so, the model is run again without giving the airport managers the ability to switch capacity. Rather, no change in capacity occurs at the beginning of Period II, ten years into the airport's operation and fifteen years from the end of the period being observed. Figure A-46 illustrates.

As before, the option's worth is found by subtracting the expected net present value of the airport with and without multi-functionality.

Table A-11: Multi-functionality Evaluation - Value of Strategy without Option

	A		B
E(NPV) [k$]	$256,779		$6,979
Gain in P2	*$148,401*		*$203,673*
Best Choice	B	$6,979	[k$]

Lacking the option to switch leads to an expected loss of US $7 million in present dollars.

Table A-12: Multi-functionality: Value of Strategy with Option

	A		B
E(NPV) [k$]	$164,128		$58,261
Gain in P2	*$241,051*		*$268,912*
Best Choice	B	$58,261	[k$]

Conversely, the value of an airport with the ability to switch its terminal capacities based on the dominant carrier is estimated at US $58 million in present dollars. Given the hypothetical data, the option is worth US $665 million; this value also represents the maximum amount that should be spent ensuring that the terminals, if designed for a total of 10 million passengers, are able to switch one-half of their capacity.

Value-at-Risk/Gain

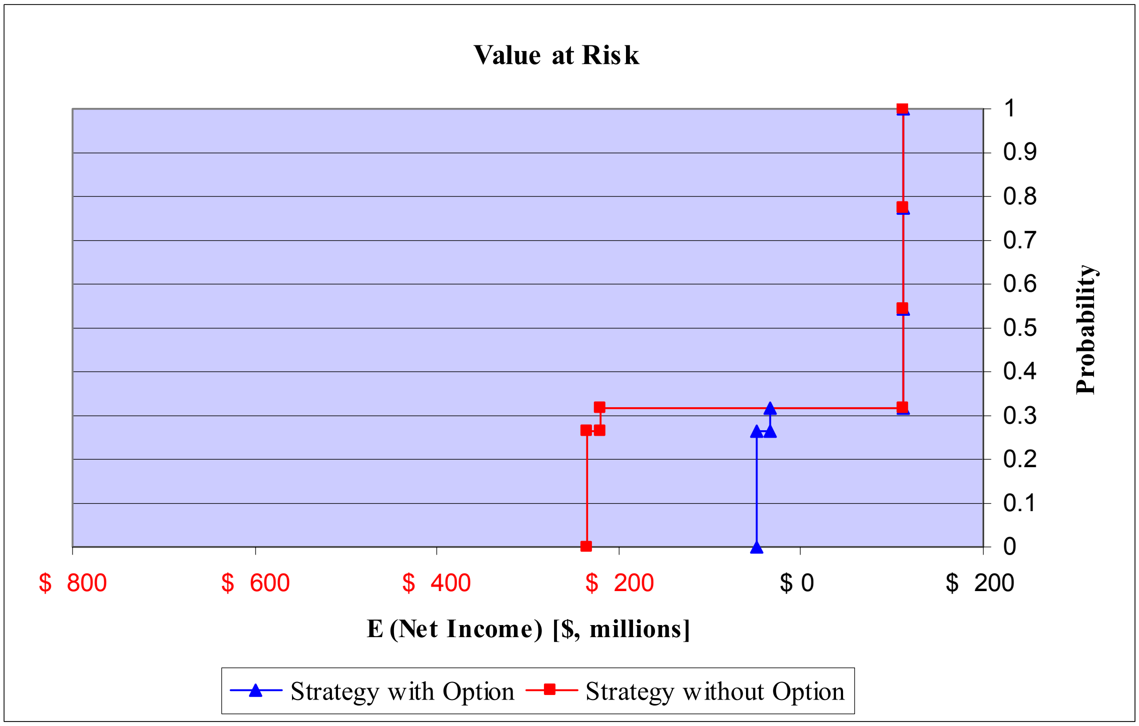


Figure A-47: New Airport Terminal Model – Multi-functionality can reduce Downside Risk

<u>Ensuring Expandability</u>

Two Strategies

Table A-13: Deferring Decisions Evaluation – Two Strategies

		Planners With Option	**Planners Without Option**
Period I	**Big NC Strategy**	No LCC Capacity 20 million for NC	No LCC Capacity 20 million for NC
	Big LCC Strategy	20 million for LCC No NC Capacity	20 million for LCC No NC Capacity
Period II	**Expand for LCC**	Either 5 million for LCC or No Change	No Change
	Expand for NC	Either 5 million for NC or No Change	No Change

Model Set-up

Capacities							
Initial Capacities (people)					Capacity Increases (people)		
Decision	LCC	NC				LCC	NC
A. Big NC	0	10,000,000	A	D	Build Big(LCC)	0	0
B. Big LCC	10,000,000	0	B	D	Build Big(NC)	0	0
C. Small Ota	[redacted]		C	E	Build Small (LCC)	0	0
				E	Build Small (NC)	0	0

Figure A-48: Ensuring Expandability – Strategy without Option

Capacities							
Initial Capacities (people)					Capacity Increases (people)		
Decision	LCC	NC				LCC	NC
A. Big NC	0	10,000,000	A	D	Build Big(LCC)	5,000,000	0
B. Big LCC	10,000,000	0	B	D	Build Big(NC)	0	5,000,000
C. Small Ota	[redacted]		C	E	Build Small (LCC)	0	0
				E	Build Small (NC)	0	0

Figure A-49: Ensuring Expandability – Strategy with Option

Model Results & Option Value

The difference in profit margins, as in previous examples, again shows the value of real options given the sample airport used. Planners who lack the ability to expand as necessary lose an expected US $7 million in present dollars (given the hypothetical data), as shown in Table A-14.

Table A-14: Ensuring Expandability – Valuing the strategy without expansion

[redacted]	Build for NC (A)		Build for LCC (B)
E(NPV) [k$]	$256,779		$6,979
Gain in P2	*$148,401*		*$203,673*
Best Choice	B	$6,979	[k$]

Designers with the option to expand, however, fare better. Table A-15 shows three cases in which expansion is desired: if planners chose to build for the non-dominant carrier in Period 1 (A1 and B2) or if the probability of revenue growth outstrips the capacity available to the airport (B1). In the first two cases, additional construction corrects for earlier errors; in the third, it allows the airport to take advantage of new growth.

Table A-15: Ensuring Expandability Evaluation - When to Expand

[redacted]	A1	A2	B1	B2
E(NPV) [k$]	$254,962	$67,837	$175,204	$101,662
Best Choice	D	E	D	D
Best Choice	Build Big	Build Small	Build Big	Build Big

This simple variation in strategy provides an additional US $83 million. This value is also the maximum amount that airport planners should spend on ensuring that the airport can expand according to the parameters laid out in Table A-13, given that the airport only remains open for 25 years. At airports that remain open for longer, however, the value of the expansion option is significantly increased.

Table A-16: Ensuring Expandability – Valuing the strategy without expansion

	Build for NC (A)			Build for LCC (B)
E(NPV) [k$]	$189,468			$78,301
Gain in P2	*$215,711*			*$288,952*
Best Choice	B	$78,301	[k$]	

Value-at-Risk/Gain

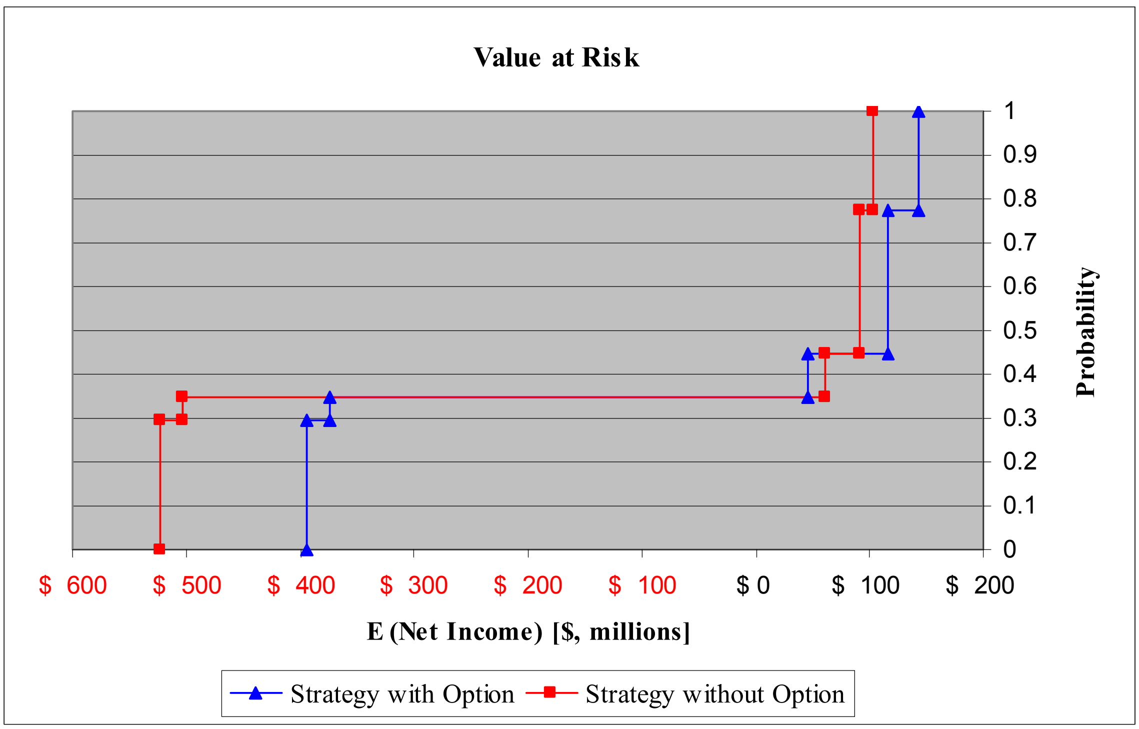


Figure A-50: New Airport Terminal Model – Expandability can shift the VaRG curve right.

A6. The New Airport Terminal Model: Regional Development Scenario Inputs

This section gives the inputs used in the theoretical Regional Development Scenario. Unless otherwise stated, the default values from the Lisbon Airport Scenario were used.

System Development

Two Strategies

Table A-17: Regional Development Scenario – Three Strategies for LCC-based Construction

	Construction Strategy	Capacity Built [Mpax]
Period I	Big LCC Strategy (A)	25 million for LCC 5 million for NC
	Medium LCC Strategy (B)	10 million for LCC 5 million for NC
	Build for Both Strategy (C)	10 million for LCC 10 million for NC
Period II	Expand if LCC dominant	20 million for LCC No change to NC
	Expand if NC dominant	No change to LCC 20 million for NC
	No Expansion	No change to LCC No change to NC

Table A-18: Regional Development Scenario – Three Strategies for LCC-based Construction given Multi-functionality

	Construction Strategy	Capacity Built [Mpax]
Period I	Big LCC Strategy (A)	25 million for LCC 5 million for NC
	Medium LCC Strategy (B)	10 million for LCC 5 million for NC
	Build for Both Strategy (C)	10 million for LCC 10 million for NC
Period II	Expand if LCC dominant	20 million for LCC No change to NC
	Expand if NC dominant	No change to LCC 20 million for NC
	Switch Capacity	5 million to LCC or 5 million to NC

Model Set-up

Capacities							
Initial Capacities (people)					Capacity Increases (people)		
Decision	LCC	NC				LCC	NC
A. Big NC	25,000,000	5,000,000	A	D	Build Big(LCC)	20,000,000	0
B. Big LCC	10,000,000	5,000,000	B	D	Build Big(NC)	0	20,000,000
C. Small Ota	10,000,000	10,000,000	C	E	Build Small (LCC)	0	0
				E	Build Small (NC)	0	0

Figure A-51: Regional Development Scenario – Strategy without Switching

Capacities							
Initial Capacities (people)					Capacity Increases (people)		
Decision	LCC	NC				LCC	NC
A. Big NC	25,000,000	5,000,000	A	D	Build Big(LCC)	20,000,000	0
B. Big LCC	10,000,000	5,000,000	B	D	Build Big(NC)	0	20,000,000
C. Small Ota	10,000,000	10,000,000	C	E	Build Small (LCC)	0	-5,000,000
				E	Build Small (NC)	-5,000,000	0

Figure A-52: Regional Development Scenario – Strategy with Switching

System Outputs

Model Results & Option Value

Table A-19: Regional Development Scenario - Valuing the strategy without Multi-functionality

	A1	A2	B1	B2
E(NPV) [k$]	$268,812	$625,448	$130,728	$141,796
Best Choice	E	E	D	E
Best Choice	Build Small	Build Small	Build Big	Build Small

C1	C2
$224,021	$262,051
E	E
Build Small	Build Small

Table A-20: Regional Development Scenario - Valuing the strategy with Multi-functionality

	A1	A2	B1	B2
E(NPV) [k$]	$317,421	$507,609	$130,728	$23,956
Best Choice	D	E	D	E
Best Choice	Build Big	Switch (to NC)	Build Big	Switch (to NC)

C1	C2
$112,288	$232,541
E	E
Switch (to NC)	Switch (to NC)

One additional model run shows the Terminal Model's preference for switching, building big, or doing nothing.

Capacities							
Initial Capacities (people)					Capacity Increases (people)		
Decision	LCC	NC				LCC	NC
A. Big NC	25,000,000	5,000,000	A	D	Build Big(LCC)	0	0
B. Big LCC	10,000,000	5,000,000	B	D	Build Big(NC)	0	0
C. Small Ota	10,000,000	10,000,000	C	E	Build Small (LCC)	0	-5,000,000
				E	Build Small (NC)	-5,000,000	0

Figure A-53: Regional Development Scenario – Third Strategy

Table A-21: Regional Development Scenario – Preference for Actions

	A1	A2	B1	B2
Preference : 1	Do Nothing (Build Small)	Switch (to NC)	Build Big (for LCC)	Switch (to NC)
Preference: 2	Build Big (for LCC)	Do Nothing (Build Small)	Switch (for LCC)	Do Nothing (Build Small)
Preference: 3	Switch (to LCC)	Build Big (for NC)	Do Nothing (Build Small)	Build Big (for NC)
	C1	**C2**		
Preference : 1	Switch (to LCC)	Switch (to NC)		
Preference: 2	Do Nothing (Build Small)	Do Nothing (Build Small)		
Preference: 3	Build Big (for LCC)	Build Big (for NC)		

Interpreting Table A-21, if A1 occurs, the Model chooses not to build in Period II; if A1 occurs, the Model chooses to switch its LCC capacity to NC capacity; if B1 occurs, the Model chooses to build big for LCC, etc. Switching provides the superior alternative in four out of six possible cases. The benefit is reflected in the VaRG curves.

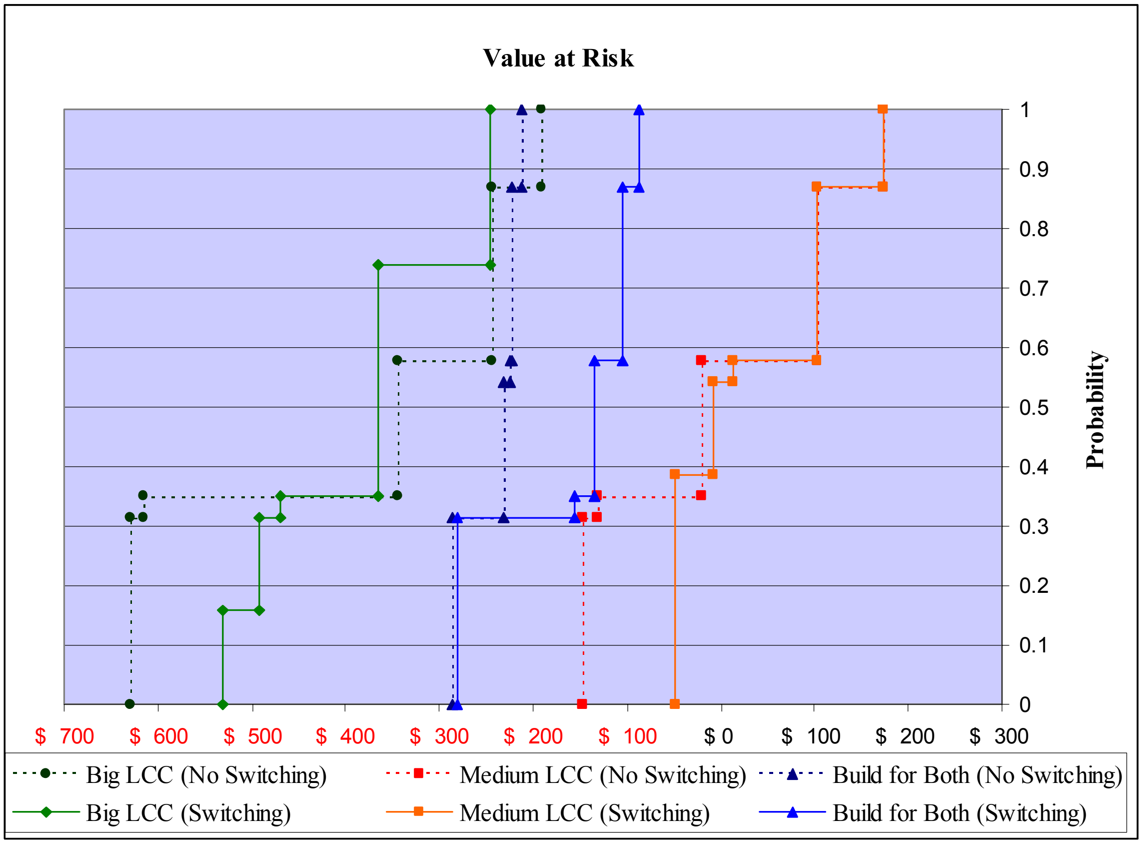


Figure A-54: Regional Development Scenario – Multi-functionality improves VaRG of LCC-based Strategies

A7. Table of Figures

A8. Table of Tables

A9. Airport Reference Codes Used

Country	City	Airport Name	IATA Code
Australia	Sydney	Sydney/Kingsford Smith Int'l	SYD
Belgium	Charleroi	Brussels/ South Charleroi	CRL
Canada	Montréal	Montréal/Mirabel Int'l	YMX
China	Hong Kong	Hong Kong Int'l	HKG
France	Paris	Paris/Charles de Gaulle Int'l	CDG
	Paris	Paris/Orly	ORY
Germany	Cologne	Cologne/Bonn	CGN
	Frankfurt	Frankfurt-Hahn	HHN
		Frankfurt/(Main) Airport City	FRA
	Munich	Munich/Franz Josef Strauss Int'l	MUC
Japan	Osaka	Osaka Int'l (Itami Airport)	ITM
		Osaka/Kansai Int'l	KIX
Netherlands	Amsterdam	Amsterdam/Schiphol	AMS
Portugal	Lisbon	Lisbon/Portela	LIS
		Lisbon/New Lisbon Int'l	-- (*NLA here*)
Sweden	Stockholm	Stockholm-Arlanda	ARN
Switzerland	Geneva	Geneva/Cointrin International	GVA
United Kingdom	Liverpool	Liverpool/John Lennon	LPL
	London	London/Heathrow	LHR
		London/Gatwick	LGW
		London/Luton	LTN
		London/Stansted	STN
	Rhoose, Wales	Rhoose/Cardiff Int'l	CWL
United States	Austin	Austin-Bergstrom Int'l	AUS
	Baltimore	Baltimore/Washington Int'l Thurgood Marshall	BWI
	Boston	Boston/Logan	BOS
	Dallas	Dallas/Fort Worth Int'l	DFW
	Denver	Denver Int'l	DIA
	Kansas City	Kansas City Int'l	MCI
	Los Angeles	Los Angeles/International	LAX
	Manchester	Manchester-Boston Regional	MHT
	New Orleans	Louis Armstrong New Orleans Int'l	MSY
	New York	New York/John F Kennedy Int'l	JFK
		New York/LaGuardia Int'l	LGA
	Newark	Newark/Liberty Int'l	EWR
	Providence	Providence/Theodore Francis Green State	PVD
	Washington, DC	Washington/Dulles Int'l	IAD
	Washington, DC	Washington/Ronald Reagan Nat'l	DCA