ASSESSING THE EFFICACY OF ADAPTIVE AIRPORT STRATEGIC PLANNING: RESULTS FROM COMPUTATIONAL EXPERIMENTS

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ABSTRACT

Airport development is increasingly difficult. One of these difficulties stems from uncertainty about future developments. Currently, airport development relies on Airport Master Planning (AMP). The goal of AMP is to provide a detailed blueprint for how the airport should look in the future, and how it can get there. However, among others because of the uncertainty about e.g. future demand, Master Plans often perform poorly. Alternatives to Airport Master Planning have emerged in the literature. The central idea of these alternatives is to have a plan that is flexible and over time can adapt to the changing conditions under which an airport must operate. We call such an approach Adaptive Airport Strategic Planning (AASP). However, AASP has not yet been applied in practice. One important reason for this lack of application is that its efficacy has not yet been established. In this paper, we apply Exploratory Modeling and Analysis, which uses computational experiments, to assess the efficacy of AASP across a large range of possible futures, for the case of Amsterdam Airport Schiphol. The results show that, given the same uncertainties, the range of outcomes from the adaptive plan is smaller then that of the Master Plan. So, the adaptive plan will expose an airport less to negative outcomes. These findings together suggest that AASP minimizes the downside risk without significantly reducing the upside potential. As such, AASP should be preferred to AMP for airport strategic planning.

Keywords: Adaptive Policy, Airport Strategic Planning, Uncertainty, Exploratory Modeling and Analysis

INTRODUCTION

Airports around the world operate in an increasingly uncertain environment. Airlines are able to change their network structures overnight. The oil price, flu epidemics, and financial and economic woes further add to the volatility of aviation demand development. Combined with tensions between economic and environmental impacts, this makes airport strategic planning a challenging task. Airport strategic planning (ASP) focuses on the development of plans for the medium to long-term development of an airport. Strategic planning is defined as 'the managerial activities that produce fundamental decisions and actions that shape and guide what the organization is, what it does, and why it does it' (Bryson, 1995). Strategic planning can be done in many different ways. In airports, the dominant approach is Airport Master Planning (AMP). AMP boils down to forecasting the future demand and then drafting a blueprint for accommodating this demand. For a while, it has been recognized that an alternative to this approach is called for (de Neufville, 2000; Burghouwt, 2007; Kwakkel et al., in press).

The alternative approach to ASP that is discussed in the literature is based on adaptability and flexibility. Instead of trying to predict future demand, which is known to be very volatile, it is recommended that plans should be able to cope with a range of demand levels. To realize this, a variety of techniques and approaches, such as real options, experimentation, flexible strategic planning, scenarios, and adaptive policymaking, have been put forward (de Neufville, 2000; Burghouwt, 2007; Kwakkel et al., in press).

The efficacy of alternatives to AMP needs to be established before any alternative is used in practice. However, the efficacy of such new infrastructure planning approaches has not been explored in depth (Hansman et al., 2006; Marchau et al., 2009). Given the societal and economic importance of airports, adequate planning is important. To use an untested approach or idea in planning future airport developments is to expose the airport and its stakeholders to many risks. In establishing the efficacy of new infrastructure planning approaches one faces a methodological problem (Dewar et al., 1993; Hansman et al., 2006). We will argue that computational experiments can be used as a method to overcome this problem.

This paper aims to provide evidence for the efficacy of the new planning approaches using computational experiments. By drawing upon readily available tools for calculating different aspects of airport performance, and combining this with a variety of different ways to generate future developments, the performance of the Master Plan can be compared to the competing adaptive plan across a wide area of plausible future developments. In Section 2, we discuss the current approach to ASP and alternatives to it in more detail. Section 3 presents the methodology that has been used. Section 4 presents the case, experimental setup, and results of the computational experiments. Section 5 discusses the results. Section 6 presents our conclusions.

HANDLING UNCERTAINTY IN AIRPORT STRATEGIC PLANNING

The current approach and its problems

The current dominant approach for the long-term development of an airport is Airport Master Planning (AMP). AMP is a formalized, structured planning process that results in a Master Plan that 'presents the planner's conception of the ultimate development of a specific airport' (ICAO, 1987). As such, the focus in AMP is on the development of plans and not on the decisionmaking process about the plans. Admittedly, the decisionmaking process is interwoven with the AMP process, but for analysis purposes we focus here on the AMP process. In the United States, the FAA has set up strict guidelines for an AMP study (FAA, 2005). Internationally, reference manuals of IATA and books about airport planning by leading scholars heavily influence AMP practices (e.g. ICAO, 1987; de Neufville and Odoni, 2003; IATA, 2004).

The goal of Master Planning is to provide a blueprint that will determine the future development of the airport (Dempsey et al., 1997; Burghouwt and Huys, 2003). A Master Plan describes the strategy of an airport operator for the coming years mainly in terms of infrastructural changes, without specifying operational concepts or management issues. AMP, as the main way to shape and determine the long-term development of an airport, has proven to be ineffective, as can be seen for example in planning failures at Amsterdam Airport Schiphol, Denver International Airport, Boston Logan Airport, and Montréal Mirabel airport (Nelkin, 1974; Nelkin, 1975; Szyliowicz and Goetz, 1995; Dempsey et al., 1997; Cidell, 2004; Kwakkel et al., 2007).

There are two main reasons for the inefficacy of AMP, namely its reliance on demand forecasting and the blueprint character of the resulting Master Plan. With respect to demand forecasting, the problem is that for a multitude of reasons, the forecasted demand fails to materialize (Ascher, 1978; Porter et al., 1991; Flyvbjerg, 2005). In the case of the aviation industry, forecasting has become more and more inappropriate due to the transition from a state-owned state-operated industry to a hybrid with both public and private organizations. Currently, aviation transport in the US and Europe is largely privatized, while other regions in the world are moving in this direction. Burghouwt (2007) has studied how airline networks have evolved in Europe over time and concludes that air traffic demand is becoming more volatile and more uncertain, implying that forecasting air traffic demand for specific airports is becoming ever more problematic. Second, Master Plans have a blueprint character (Burghouwt and Huys, 2003). The plan is drafted during the planning phase and is then handed over for implementation. During the implementation phase, the plan is implemented without much consideration for changing conditions. So, the Master Plan is static in nature and leaves little room for adapting to changing conditions. The inability to forecast future demand with sufficient precision and the static character of Master Plans together render AMP problematic for ASP.

Adaptive Airport Strategic Planning

In response to the problematic nature of AMP, a number of approaches have emerged (e.g. de Neufville, 2000; Burghouwt, 2007; Kwakkel et al., 2007). Recently, a synthesis of these approaches, called Adaptive Airport Strategic Planning (AASP), has been put forward. This synthesis integrates the different ideas that were discussed in the air transport literature into a single approach (Kwakkel et al., in press). The central idea of AASP is to have a plan that is flexible and over time can adapt to the changing conditions under which an airport must operate. AASP offers a framework and stepwise approach for making such adaptive or flexible plans.

The initial idea of an adaptive plan is found almost a century ago. Dewey (1927) put forth an argument proposing that policies be treated as experiments, with the aim of promoting continual learning and adaptation in response to experience over time (Busenberg, 2001). Early applications of adaptive policies, can be found in the field of environmental management (Holling, 1978). Motivated by the complexity of the environmental system, managers resort to controlled experiments aimed at increasing their understanding of the system (McLain and Lee, 1996). Adaptive policies are designed from the outset to test clearly formulated hypotheses about the behavior of an ecosystem being changed by human use (Lee, 1993). A similar attitude is also advocated by Collingridge (1980) with respect to the development of new technologies. Given ignorance about the possible side effects of technologies under development, he argues that one should strive for correctability of decisions, extensive monitoring of effects, and flexibility. More recently, Walker et al. (2001) developed a structured, stepwise approach for planned adaptation. This approach advocates that plans should be flexible. One should take only those actions that are non-regret and time-urgent and postpone other actions to a later stage. In order to realize this, it is suggested that a monitoring system and a pre-specification of responses when specific trigger values are reached should complement the basic plan.

Although a generic approach to policymaking, the main area of research on adaptive policymaking has been in strategic planning for transport systems (Marchau and Walker, 2003; Agusdinata et al., 2007; Kwakkel et al., 2007; Marchau et al., 2009). AASP is a synthesis of Walker et al. (2001), de Neufville (2000), Burghouwt (2007), and Kwakkel et al. (2007). It has been presented as an approach specific for ASP, but in principle it can also be applied to other infrastructure planning problems. Figure 1 shows the AASP framework.

In short, in Step I, the existing conditions of an airport are analyzed and the goals for future development are specified. In Step II, the way in which this is to be achieved is specified. This basic plan is made more robust through four types of actions specified in step 3: (i) *mitigating actions* are actions to reduce the *certain* adverse effects of a plan; (ii) *hedging actions* are actions to spread or reduce the risk of *uncertain* adverse effects of a plan; (iii) *seizing actions* are actions taken to seize certain available opportunities; and (iv) *shaping actions* are actions taken to reduce the chance that an external condition or event that could make the plan fail will occur, or to increase the chance that an external condition or event that could make the plan succeed will occur. Even with the actions taken in step III, there is still the need to monitor the performance of the plan and take action if necessary. This is called contingency planning and is specified in step IV. Signposts specify information that should be tracked in order to determine whether the plan is achieving its conditions for success. Critical values of signpost variables (triggers) are specified, beyond which actions should be implemented to ensure that the plan keeps moving the system in the right direction and at a proper speed. There are four different types of actions that can be triggered by a signpost: (i) *defensive actions* are taken to clarify the basic plan, preserve its benefits, or meet outside challenges in response to specific triggers that leave the basic plan remains unchanged; (ii) *corrective actions* are adjustments to the basic plan; (iii) *capitalizing actions* are actions trigger to take advantage of opportunities that improve the performance of the basic plan; and (iv) a *reassessment* of the plan is initiated when the analysis and assumptions critical to the plan's success have clearly lost validity. For a more detailed explanation of this framework, see (Walker et al., 2001; Marchau et al., 2009; Kwakkel et al., in press).

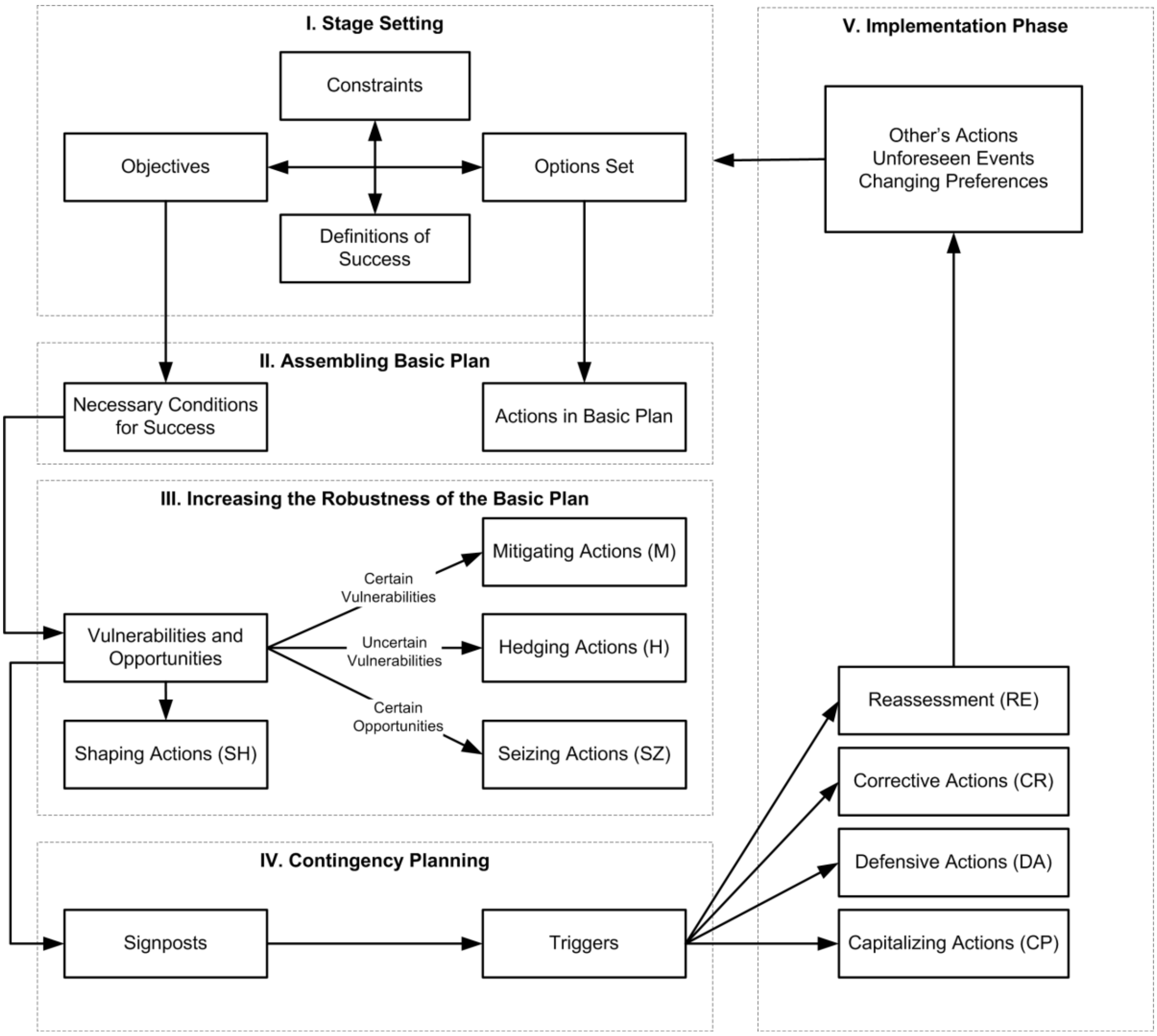

Figure 1: The steps of adaptive airport strategic planning (Kwakkel et al., in press)

EXPLORATORY MODELING AND ANALYSIS FOR EVALUATING THE EFFICACY OF AASP

New infrastructure planning approaches for handling the full range of uncertainties have seen limited application (Hansman et al., 2006). One reason for this is that the validity and efficacy of these new planning approaches has not been explored in depth (Hansman et al., 2006; Marchau et al., 2009). There is currently no best practice for evaluating the efficacy of new planning approaches (Dewar et al., 1993; Hansman et al., 2006). In establishing the efficacy of new infrastructure planning approaches one faces a methodological problem for ”nothing done in the short term can ‘prove’ the efficacy of a planning methodology; nor can the monitoring, over time, of a single instance of a plan generated by that methodology, unless there is a competing parallel plan” (Dewar et al., 1993). Given the importance of infrastructure to society, using new unproven infrastructure planning approaches poses a significant risk.

Following Frey and Dym (2006), we draw an analogy with medicine. Medicine has a well established approach for gathering evidence about the efficacy of new treatments. Frey and Dym (2006) argue that this approach can be used to inform testing design approaches. We argue that this same analogy can also be adopted as a methodology for determining the efficacy of new infrastructure planning approaches. Table 1 summarizes the analogy interpreted in this way. It specifies the different levels of evidence used in medicine and the analogue that can be used when testing infrastructure planning approaches.

Table 1: Types of evidence used to develop and validate medical treatments and infrastructure planning approaches (adapted from Frey and Dym, 2006)

Evidence used to develop / validate medical treatment	**Evidence used to develop / validate infrastructure planning approaches**
Theory	Theories (e.g. decision science, cognitive science, political science, organizational behavior, policy analysis)
Animal Models	Computational experiments of plans across an ensemble of futures (Bankes, 1993; Bankes, 2009) Simulation gaming with students (Mayer and Veeneman, 2002)
In Vitro Experiments	Simulation gaming with actual decisionmakers (Mayer and Veeneman, 2002)
Natural Experiments	Case studies of successful long-term infrastructure plans
Clinical Trials	?

Given that we use computational experiments in this paper for assessing the efficacy of AASP, we now provide some more background on this method. The basic approach for testing AASP, using EMA is: (i) develop a fast and simple model of the system of interest; (ii) generate an ensemble of future worlds; (iii) specify a traditional Master Plan and an adaptive plan; and (iv) calculate and compare the performance of both plans across an ensemble of future worlds using the fast and simple model.

Most models are intended to be predictive and use consolidative modeling techniques, in which known facts are consolidated into a single 'best estimate' model. The consolidated model is subsequently used to predict system behavior (Hodges, 1991; Hodges and Dewar, 1992). In such uses, the model is assumed to be an accurate representation of that portion of the real world being analyzed. However, the consolidative approach is valid only when there is sufficient knowledge at the appropriate level and of adequate quality available – that is, only when we are able to validate the model in a strict empirical sense. We can validate models only if the situation is observable and measurable, the underlying structure is constant over time, and the phenomenon permits the collection of sufficient data (Hodges and Dewar, 1992). However, in most real-world cases of decisionmaking, the systems are complex and their future structure is unknown. The use of predictive models for such systems is problematic. Many scientists have realized this. Some claim "the forecast is always wrong" (Ascher, 1978); others say such predictive models are "bad" (Hodges, 1991; Hodges and Dewar, 1992)., "wrong" (Sterman, 2002), or "useless" (Pilkey and Pilkey-Jarvis, 2007), which raises the question whether models can be used at all in decisionmaking under deep uncertainty (situations in which decisionmakers do not know or cannot agree on a system model, the prior probabilities for the uncertain parameters of the system model, and/or how to value the outcomes (Lempert et al., 2003)). Deep uncertainty is becoming more and more common, and new tools are needed to deal with deep uncertainty.

Even if the consolidative modeling approach cannot be used, there is normally a wealth of information, knowledge, and data available that can be used to inform decisionmaking. Exploratory Modeling and Analysis (EMA) is a research methodology that uses computational experiments to analyze complex and uncertain systems (Bankes, 1993; Agusdinata, 2008). EMA specifies multiple models that are consistent with the available information. Instead of building a single model and treating it as a reliable representation of the information, an ensemble of models is created and the implications of these models are explored. A single model run drawn from this set of models is not a prediction. Rather, it provides a computational experiment that reveals how the world would behave if the assumptions any particular model makes about the various uncertainties were correct. By conducting many such computational experiments, one can explore the implications of the various assumptions. EMA aims at offering support for exploring this set of models across the range of plausible parameter values and drawing valid inferences from this exploration (Bankes, 1993; Agusdinata, 2008). From analyzing the results of this series of experiments, analysts can draw valid inferences that can be used for decisionmaking, without falling into the pitfall of trying to predict that which is unpredictable.

The consolidative modeling approach is valid only when there is sufficient knowledge at the appropriate level and of adequate quality available. When dealing with long-term infrastructure planning, these conditions are not met, so using such a consolidative approach might produce erroneous results (Dewar and Wachs, 2006; Van Geenhuizen et al., 2007; Marchau et al., 2009). However, in such situations there still is a wealth of knowledge and information available that supports a set of structurally different models across a range of parameter values, suggesting that EMA can be used. In the context of EMA, a computer model can be used as a platform for computational experiments, as lab equipment that maps specific inputs into output about system behavior (Bankes et al., 2002; Bankes, 2009). Using models as lab equipment has implications for model design: models need to be modular so that a variety of hypotheses about system structure can be implemented, tested, and compared (Bankes, 2009).

In the context of assessing the efficacy of new infrastructure planning approaches, computer models can be used as surrogates for the real world system. By comparing the performance of traditional and new style plans as calculated by the computer models, one can reason about how these plans would behave in the real world. However, given that infrastructure planning is decisionmaking about the future, there are significant uncertainties present. There is simply not enough knowledge to accurately forecast the future, the models of large infrastructure systems are often contested, and there are a variety of value-systems involved from the different stakeholders that are also bound to change over time. The performance of the plans derived from the different planning approaches needs to be assessed across these uncertainties. Therefore, when using simulation models as animal models for assessing the efficacy of infrastructure planning approaches EMA is an appropriate method.

APPLICATION: STRATEGIC PLANNING FOR AMSTERDAM AIRPORT SCHIPHOL

In this paper, we apply EMA to assess the efficacy of AASP across a large range of possible futures for a specific case. Some work on assessing the efficacy of AASP has already been carried out. Kwakkel et al. (2007) present a comparison between a real world static Master Plan for Amsterdam Airport Schiphol (AAS) adopted in 1995 and a fictitious adaptive version of the same plan. This comparison suggests that the adaptive version of the plan could have produced preferable results over the period from 1995 to 2007. The next step in validation of the AASP approach is to use the results of the theoretical comparison in a quantitative experiment to test the performance of a traditional Master Plan versus an adaptive strategic plan across a large ensemble of futures through EMA. An analysis of the resulting outputs can reveal the differences in performance between a traditional Master Plan and an adaptive plan for the different futures. By exploring these in more depth, insight can be gained into if and when each plan would perform better.

Background

For an effective comparison of the performance of AMP versus AASP, a single in–depth case is preferred over several small cases. The efficacy of the two approaches to ASP is to be tested across a range of uncertainties, because the handling of uncertainties by a given planning approach determines the efficacy to a large extent. These uncertainties should cover the full range of uncertainties to which airports around the world are exposed. We choose to use the current challenges Schiphol is facing in its long–term development as our case. As outlined below, Schiphol faces a range of uncertainties that could affect the airport in different ways. In addition, we are familiar with the current situation of Schiphol. The uncertainties the airport currently faces have been studied recently (Kwakkel et al., 2008), a multitude of policy documents from multiple stakeholders is readily available, and the data necessary to quantify a model for calculating airport performance metrics is also available.

Aviation demand has experienced unprecedented growth since the early 1990's, fuelled by privatization and liberalization of the aviation industry. Amsterdam Airport Schiphol has benefited from this growth and has evolved into one of the European Union's major hubs. Since 1990, Schiphol has expanded its runway system and its terminal. Parallel to the increasing number of passengers and flights handled at Schiphol, negative external effects have also increased, resulting in regulations concerning noise, emissions, and third-party risk. This situation causes increasing tension between capacity, environment, and safety at and around the airports. Currently, Schiphol's position as a hub within Europe is under pressure. In 2006, Schiphol was surpassed by Madrid's Barajas Airport and now ranks as Europe's fifth airport in terms of air transport movements. The merger of Air France and KLM has resulted in the threat that KLM, Schiphol's hub carrier, which is responsible for 52% of the scheduled aircraft movements at the airport, might move a significant portion of its operations to Charles de Gaulle Airport. The other major airports in Europe are planning on expanding their capacities or are developing dual airport systems. Together, this makes the long-term planning for Schiphol both urgent and problematic.

The ensemble of models

In order to quantitatively explore and compare the performance of a Master Plan and an adaptive plan, one or more models are needed. We have chosen to have a variety of *generators* for the external scenario variables, while we use a single model for calculating airport performance for each of the scenarios. This approach is motivated by the fact that there is relatively minor uncertainty about the internal functioning of an airport, while there is significant uncertainty about future, external developments (de Neufville and Odoni, 2003; Burghouwt, 2007). Figure 2 shows the basic structure of the model that is used. A given model structure consists of several generator components and the airport performance analysis component. For each of the generators, several structurally different versions are available.

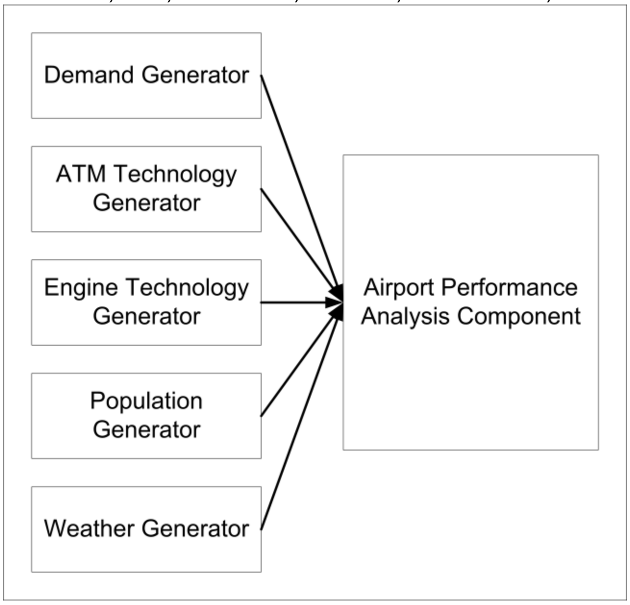

Figure 2: Conceptual design of the model

Airport performance analysis component

The airport performance analysis component is the Fast and Simple Model for Airport Performance Analysis (FASMAPA) (Kwakkel et al., 2009). It is designed in such a way that it uses existing tools and techniques where possible. In addition, the design of the model allows for easily adding tools, and for swapping one tool for another. In this respect, the design follows the key principles for airport decision support outlined by Wijnen et al. (2008), which fit with the specific requirements imposed on models when they are used as 'lab equipment' (Bankes, 2009). In response to these requirements, the model has a modular design. The Domain Module contains the logic and data that describe the inner workings of the airport system, the external forces, and the different policies. The Analysis Module contains the logic for calculating the different airport performance metrics. The elements in this module will gather the required input data and process the results. However, the actual calculations are delegated to the specific tools in the Tools Module. The Tools Module contains the logic for running the tools. Table 2 specifies the tools that are used to calculate each of the metrics. Table 2 specifies the tools that are used to calculate each of the metrics. As outcomes of interest, we used size of the 65 LDN contour for noise (LDN is a metric for averaging day and night flights by penalizing night flights), Average Casualty Expectance (ACE) for third-party risk, Practical Annual Capacity (PANCAP) utilization for the airport's physical capacity, latent demand for unaccommodated demand, and cumulative CO emissions for environmental impacts. FASMAPA has been implemented using the object oriented programming language Python. For more details on FASMAPA and its validation, see Kwakkel et al. (2009).

Table 2: Tools integrated in FASMAPA

Airport Performance Criterion	Performance Metric	Tool
Capacity	Practical Annual Capacity (PANCAP)	FCM – FAA Airfield Capacity Model, which is an extension of the classic Blumstein model (de Neufville and Odoni,

		2003)
Noise	Size of Noise Contours (Km^2)	AEM – Area Equivalent Method, a model that approximates Integrated Noise Model results (FAA, 2008)
Emissions	CO Emissions (Tons)	EDMS – FAA required tool for emission analysis
External Safety	Average Casualty Expectancy (ACE)	NATS – developed by the National Air Traffic Services

The generators

FASMAPA calculates airport performance for a given set of inputs on a yearly basis. By providing input for several years, airport performance over time can be calculated. In order to generate these input parameters, FASMAPA has been complemented with a set of generators that generate its inputs. A specific combination of generator components could be called a 'scenario generator' (Lempert et al., 2003). This scenario generator allows for generating demand volumes, wind conditions, technological developments, and changes in demographic patterns around the airport. Table 3 summarizes the uncertainties that we explored with FASMAPA and the scenario generator. Where information on the ranges was available, the source is given.

Table 3: Overview of the uncertainties explored

Type of Uncertainty	**Variations Examined**
Model structure uncertainties	
Demand	– Lognormal random walk
Long-haul vs. short-haul aircraft mix	– Uniform random walk
Population	– Logistic growth
ATM technology	– Exponential performance increase
Engine technology (noise/emissions)	– Exponential performance increase
Parameterization of structural uncertainties	
Lognormal random walk for demand	
Uniform random walk of long-haul/short haul ratio	
Logistic population growth (de Jong and Hilderdink, 2004)	Population size over 30 years, range: 17-20 million
Exponential ATM technology development	ATM technology improvement over 30 years, range: 0.85-1
Exponential engine technology development (De Haan, 2007)	Engine technology improvement over 30 years, range: 0.65-1
Parametric Uncertainties	
Weather (KNMI, 2006)	Percentage change in days with severe wind conditions per year, range: -1% - +4%

Burghouwt (2007) has shown that aviation demand in Europe has become much more volatile since the introduction of privatization and liberalization. A similar argument can also be made for the United States. This implies that there is significant uncertainty about the size and composition of future demand. To capture the volatile character of the demand development since the introduction of privatization and privatization, we have chosen to model demand as a random walk. Each year, a random number is drawn representing the change in demand. Last year's demand is multiplied by this change percentage, resulting in the demand for the next year. Using such random walks is common practice, for example in evaluating options on the stock market.

In order to adequately parameterize the random walk, we downloaded information about the top 30 airports in the world over the last eight years from the Website of Airports Council International. From this information, we extracted data pertaining to the yearly growth percentage. We next fitted several statistical distributions to the resulting dataset. We investigated three alternative distributions: the Cauchy, the Gamma, and the Lognormal. The Cauchy is a so-called 'thick tail' distribution, which can be used to simulate "black swans" – highly surprising high impact events. The Gamma distribution is mean reversing, which has often been used to model rainfall amounts. The lognormal is frequently used to model unrelated multiplicative effects.

Table 4 shows the log likelihood for each of these distributions given the data. Figure 3 shows the probability density function for each of the three statistical models superimposed on the histogram of the source data. If the only criterion for choosing the distribution was the quality of fit as expressed by the log likelihood, the Cauchy distribution would be chosen. However, there is a problem with using this distribution: it has theoretically an infinite variance. In our case, this would mean that a Cauchy random walk might result in a decrease of demand of more than 100%. This is clearly impossible. Given the small difference in terms of quality of fit, we have chosen to use a lognormal instead, which has only a marginally less good fit.

Table 4: Quality of fit to empirical data on yearly percentage growth in demand (2000-2008) of the top 30 airports

Distribution	**Log Likelihood**
Cauchy	-777.6
Gamma	-785.1
Lognormal	-779.8

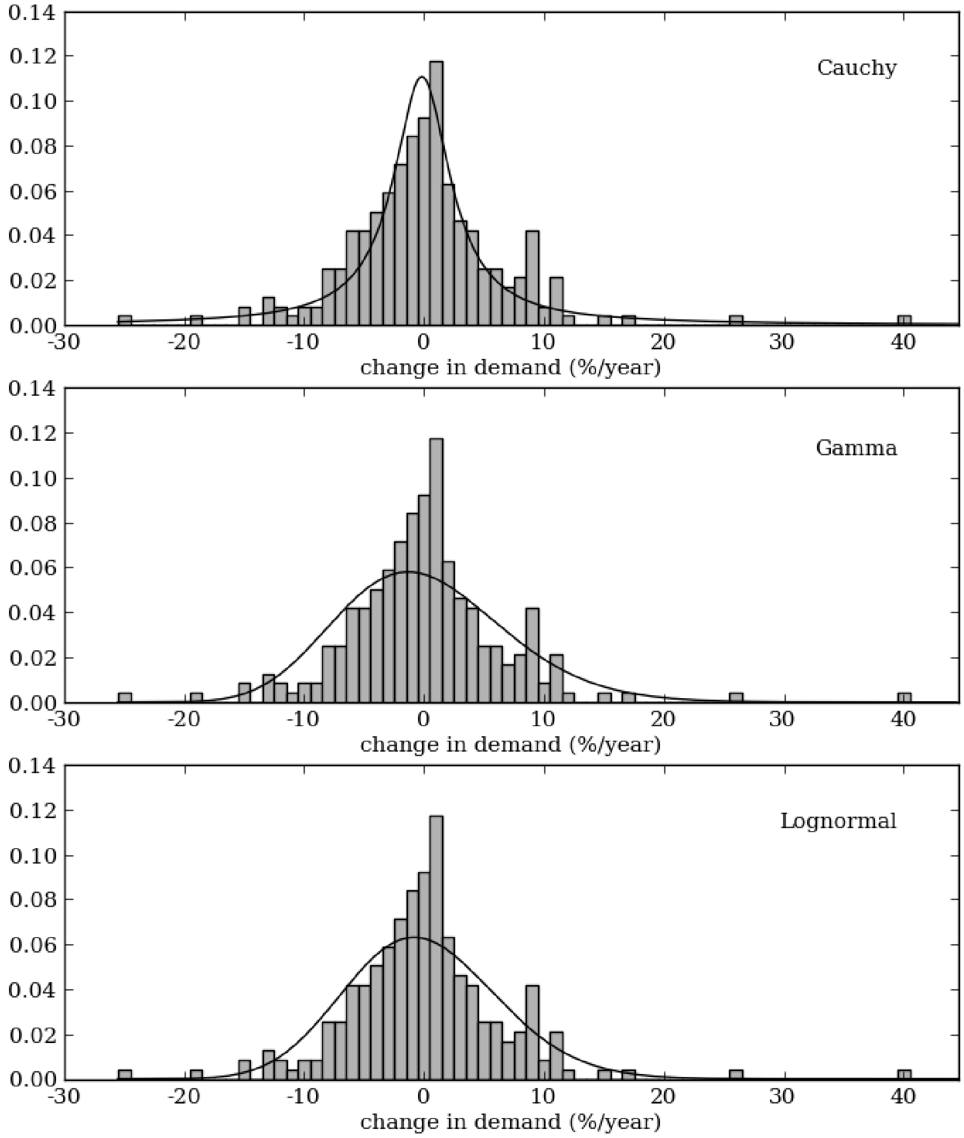

Figure 3: Histogram of the ACI demand growth data with the Probability Density Function for each distribution superimposed

The Master Plan and the adaptive plan

In The Netherlands, currently, a variety of stakeholders, such as the Ministry of Transport, the Schiphol Group, municipalities around Schiphol, and Netherlands Air Traffic Control, are in the process of drafting a plan for the long-term development of Schiphol. In this case study, we approach the problem from the perspective of this network of actors, which is responsible for the governance of Amsterdam Airport Schiphol. We chose to use a planning horizon of thirty years, consistent with advice given to Schiphol with respect to their planning horizon (CPB et al., 2007). The main goals of this governance network are: (1) to create room for the further development of the network of KLM and its Skyteam partners, and (2) to minimize (and, where possible, reduce) the negative effects of aviation in the region (Schiphol Group and LVNL, 2007). There are several types of changes that are currently being considered by the governance network in order to achieve these goals. Among the options that are being considered are:

- Add a new runway parallel to one of the existing runways
- Move charter operations out of Schiphol (i.e.., to Lelystad and Eindhoven, which have a planned capacity of roughly 70,000 operations per year (Schiphol Group, 2007; Rijksoverheid, 2009))
- Limit available slots

For the Master Plan, we assume that Schiphol will add the new runway and that it will become operational in 2020. Furthermore, up to 70,000 operations will be moved away from Schiphol. We assume that this will be done over the course of five years, from 2015 to 2020. No slot limitation will be implemented, because it is assumed that there is enough environmental capacity available to accommodate the expected demand.

For the adaptive plan, the basic plan includes planning for all the infrastructure options without beginning to build any of them. The basic plan is made more robust through the actions outlined in Table 5. The contingency plan is outlined in Table 6. With respect to the reassessment actions, if these are triggered they will be recorded, but the model run will still be completed and the outcomes of interest for that run will be recorded as normal. With respect to the actions that are taken to influence technological development, we assume they are taken; the uncertainty about their effectiveness is included in the model through the ability to generate a range of possible technological improvements via the scenario generator.

Table 5: Increasing the robustness of the basic plan

Vulnerabilities and Opportunities	Hedging (H) and Shaping (SH) Actions
Demand for air transport grows faster than forecast.	**H**: Prepare Lelystad and Eindhoven airports to receive charter flights
Population density increases in the area affected by noise	**H:** Test existing noise abatement procedures, such as the continuous descent approach, outside the peak periods (e.g. at the edges of the night) **SH:** Maintain land use reservation that allows for building the new runway
Noise from flights increases	**SH:** Negotiate with air traffic control on investments in new air traffic control equipment that can enable noise abatement procedures, such as the continuous descent approach **SH:** Invest in R&D, such as noise abatement procedures
Wind conditions change due to climate change	**H:** Have plans ready to quickly build the sixth runway, but do not build it yet. If wind conditions deteriorate, start construction

Table 6: The adaptive part of the plan

Vulnerabilities and Opportunities	Monitoring and Trigger System	Actions (Reassessment (RE), Corrective (CR), Defensive (DA), Capitalizing (CP))
Demand for air transport grows faster than	Monitor the growth of Schiphol in terms of aircraft movements. If this exceeds 450.000 operations, start building the new runway.	**CP:** Begin to implement the plan for the new runway **CR**: Move a portion of the

Vulnerabilities and Opportunities	Monitoring and Trigger System	Actions (Reassessment (RE), Corrective (CR), Defensive (DA), Capitalizing (CP))
forecast.	The new runway becomes available five years after this trigger is reached. If demand approaches 510.000 aircraft movements, activate CR action. If it exceeds 510.000, trigger RE.	operations to Lelystad and Eindhoven. **RE**: Reassess entire plan
Area affected by noise increases	Monitor area affected by noise. If area affected by noise increases by 20% compared to start year, take DA-action; by 50%, take CR-action; by 75%, take RE-action. If area decreases by 20%, take CP-action.	**DA:** Slow down of growth by limiting available slots **CR:** Slow down of growth by limiting available slots even more **RE:** Reassess entire plan **CP:** Make new slots available.
Wind conditions change due to climate change	Monitor the usage percentage of the cross-wind runway, If this increases by more then 10 percent compared to the start year, take DA action.	**DA:** Begin to implement the plan for the new runway. If this action is taken, the new runway becomes available five years later.

Results

First, given the ranges of uncertainties, what is the range of outcomes that both the Master Plan and the adaptive plan can generate? If an adaptive plan is any good, the range of outcomes from the adaptive plan should be smaller than that for the Master Plan; or, put differently, the risks associated with the adaptive plan should be smaller. Second, how does the variance in outcomes across all the cases differ between the two plans (a smaller variance implies less risk)? In order to answer these questions, we generated 40 cases across the different uncertainties using Latin Hypercube sampling. Next, each case was run fifty times per policy, where each run generated a different random walk for demand. Figure 4 shows what fifty different random walks for demand could look like over the 30-year period, in terms of landings and take-offs (LTO).

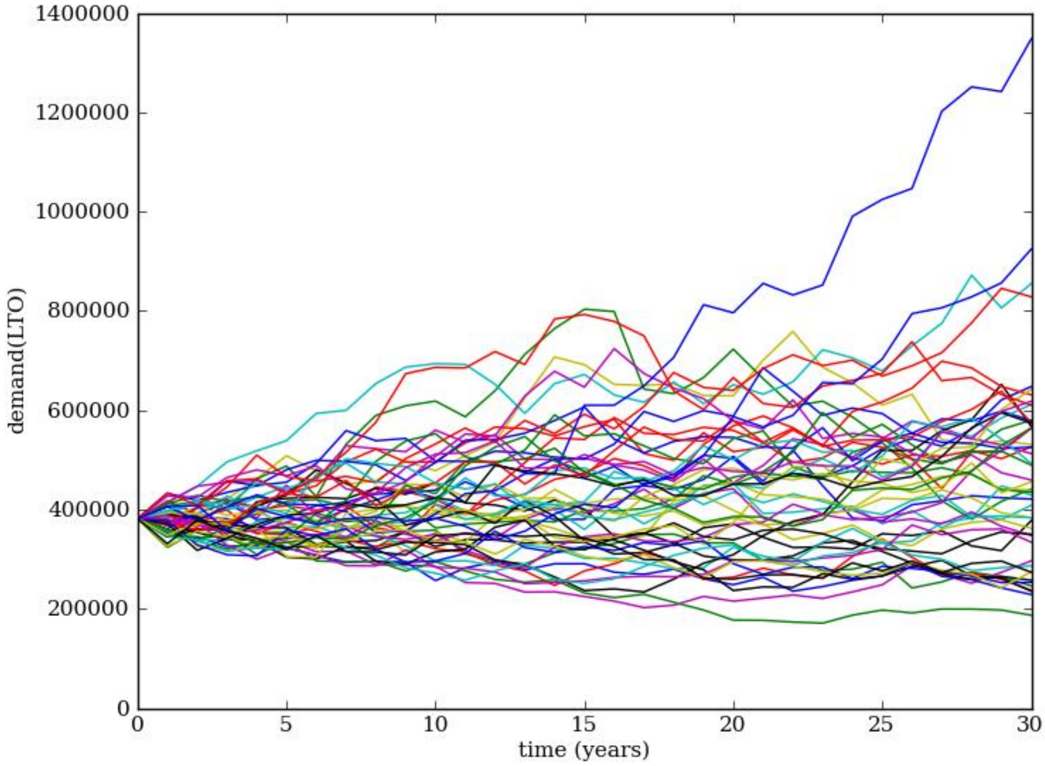

Figure 4: Fifty random walks for demand

Table 7 shows the lower and upper bound for each of the performance indicators across all the cases, split out per type of plan. On the lower bound, we observe that the Master Plan has lower values. On the upper bound the situation is reversed. From this table, it can be concluded that an adaptive plan has a smaller bound on all outcomes of interest except on latent demand. The results for latent demand are explained by the fact that the adaptive plan has triggers in place to limit the size of the noise contour. If these are triggered, less demand is accommodated, thereby increasing latent demand.

Table 7: Performance bounds of the Master Plan and the adaptive plan

	Lower Bound		**Upper Bound**	
	Master Plan	**Adaptive Plan**	**Master Plan**	**Adaptive Plan**
Size of 65 LDN contour after thirty years (km^{2})	2.4	6.7	44.2	37.8
Max. size of 65 LDN contour (km^{2})	17.3	17.3	44.9	40.0
Cumulative ACE (ACE)	0.6	0.7	2.4	1.9
PANCAP utilization after	0.06	0.3	1.2	1.3

thirty years				
Max PANCAP utilization	0.9	0.9	1.5	1.3
Accumulated latent demand (flights)	0	0	540449	948461
Cumulative CO emission (kg)	15184	15602	79665	76530

Figure 5 shows histograms for six of the seven performance indicators. (Latent demand has been left out because is not informative (99% of the cases fall into the last bin in the histogram, close to one)). Each of the performance indicators has been normalized, using the maxima and minima from Table **7**, so that they scale between 0 (bad) and 1 (good). Examining these histograms, we observe first that there are fewer cases where the available capacity is under utilized. That is, the adaptive plan results in avoiding unnecessary investments in new runway capacity if the demand levels do not require an additional runway. If we now compare the size of the 65 LDN noise contour, the Average Casualty Expectancy, and CO emissions, it appears that the Master Plan is performing better. The Master Plan has more cases closer to 1. However, the Master Plan explicitly moves operations away from Schiphol, while the adaptive plan does so only if necessary. As a result, even in low demand situations, up to 70,000 operations will be moved to other airports in the Netherlands under the Master Plan. This explains the apparent better performance of the Master Plan.

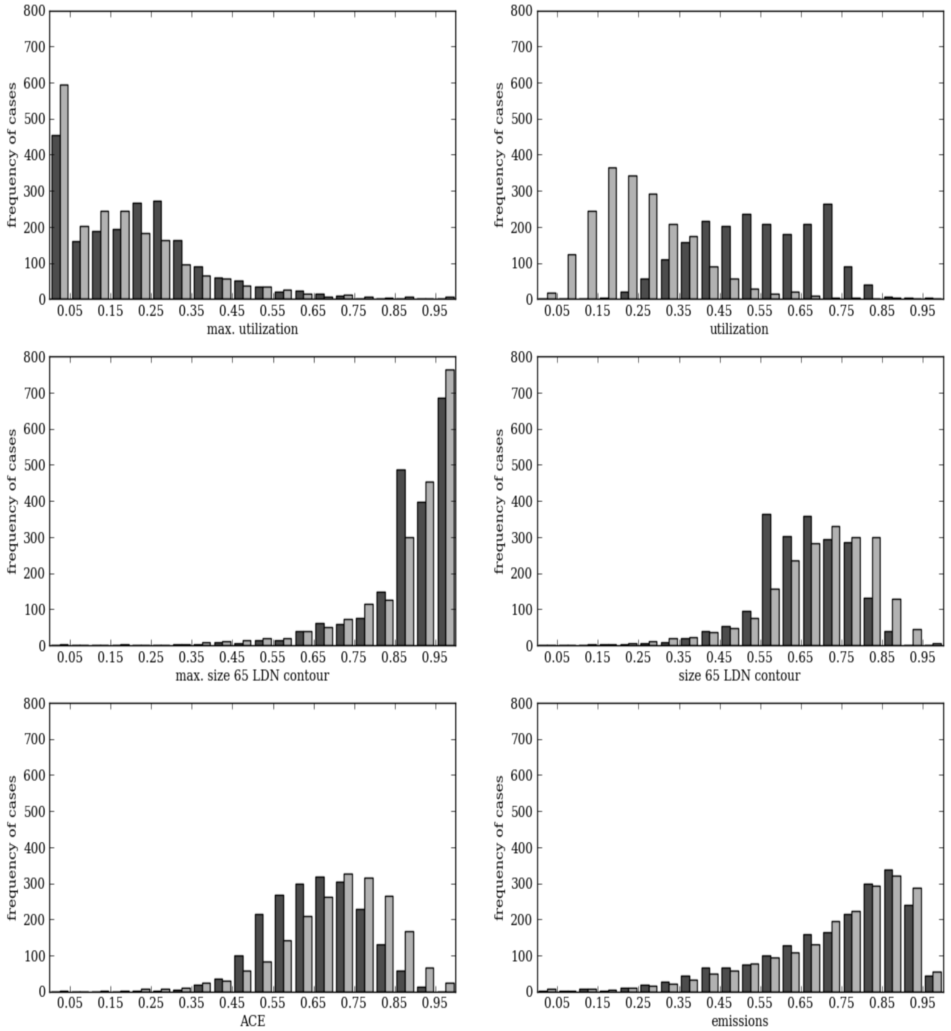

Figure 5: Histograms of the Performance Indicators (light grey is the Master Plan; dark grey is the adaptive plan)

If we take Figure 5 and Table 7 together, we draw the following conclusions. First, the variance in performance, understood as the upper and lower bound, for almost all the performance indicators is larger for the Master Plan than for the adaptive plan. Thus, a Master Plan exposes an airport to more risk about the expected outcomes. Furthermore, in the case study, there is a trade-off between utilization and the environmental impacts. Under the adaptive plan, a significant improvement of utilization is achieved, while potentially slightly decreasing the environmental performance at Schiphol. However, if the analysis would also cover Lelystad and Eindhoven (which should be considered when evaluating the performance of the Netherlands' overall civil aviation system), this slight decrease in environmental performance under the adaptive plan would disappear, for it is explained by the fact that the Master Plan will move 70.000 operations to these airports. Furthermore, the slight decrease in environmental performance only occurs in a number of cases, not in all. Since the upper bound of the Master Plan is higher on all environmental performance indicators, it is plausible that if demand is quite high, the environmental performance of the Master Plan will be worse than in case of the adaptive plan.

So far, we have examined only the individual performance indictors. However, we would also like to get insight into the difference in overall performance. In order to do so, we use ACE, PANCAP utilization, latent demand, size of the 65 LDN contour, and cumulative CO emissions as performance indicators. We normalize these performance indicators, using the maxima and minima from Table 7, so that they scale between 0 (bad) and 1 (good). These five performance indicators together are a performance vector that describes the performance of a plan. We then define the performance of a plan as the length of the performance vector, using the Euclidian norm. Figure 6 shows the resulting histogram. Again, dark grey is the adaptive plan and light grey is the Master Plan. This picture clearly shows that, in terms of overall performance, the adaptive plan reduces the downside outcomes, while only sacrificing a bit of upside performance.

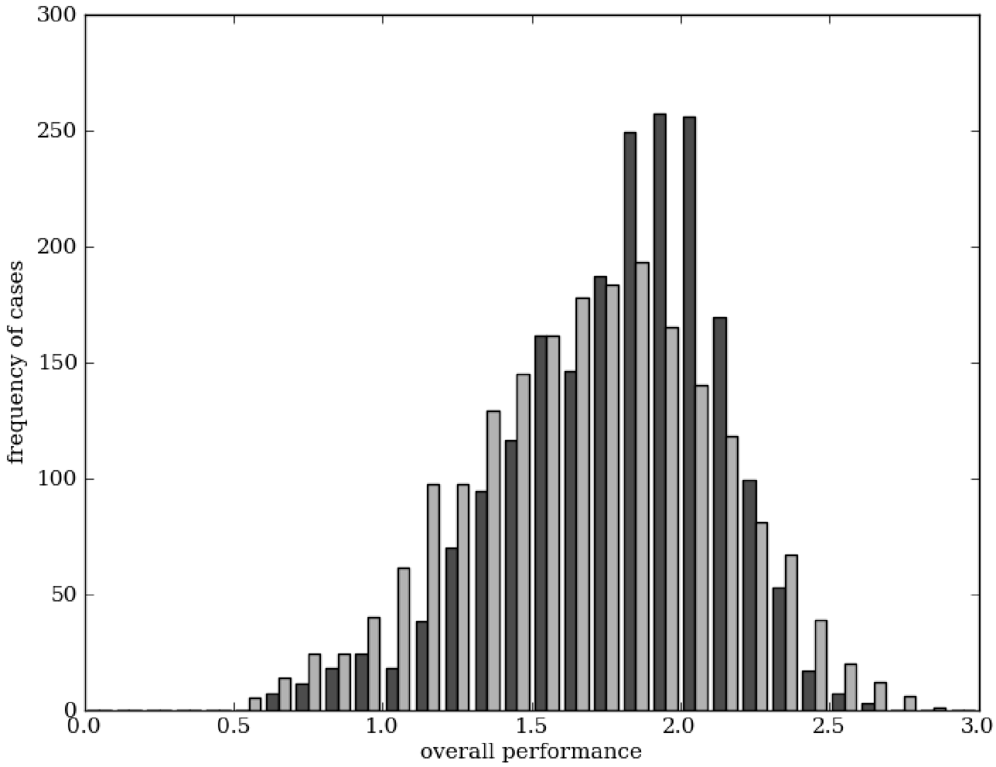

Figure 6: Histogram of overall performance

DISCUSSION

From the foregoing, we conclude that AASP minimizes the downside risk without significantly reducing the upside potential, given a variety of uncertainties. Since most airports operate in an increasingly uncertain environment, this strongly suggests that airports should start to adopt adaptive approaches for their planning. There are several possible objections to this conclusion. First, some might argue that in real world Master Planning, if the actual developments were to deviate from those underlying the Master Plan, changes would probably be made to the plan. Such *ad hoc* changes are not taken into account in the computational experiments. There is some merit to this argument. It is correct that we have not modeled the stakeholders that jointly govern the airport's development and their response to actual developments. *Ad hoc* changes to a Master Plan come out of this arena of stakeholders after, often lengthy, re-negotiations. How to include this process is an open question. One option would be to use an agent based model representing the different actors. Alternatively, simulation gaming could be combined with computational experiments to reveal how such negotiation processes might work out. This, in fact, is implied by the medical analogy introduced in Section 0. As argued there, evidence for the efficacy of new infrastructure planning approaches comes from multiple sources, only one of which is computational experimentation. For this evidence to be valid, the models need only a partial resemblance to the phenomenon of interest. As such, this objection, although not without grounds, only implies that further evidence is needed for the efficacy of AASP − specifically with respect to the stakeholder arena and its behavior in case of both the adaptive plan and the Master Plan.

Second, the analysis did not cover the costs of either version of the plan. For a more comprehensive comparison, these costs should be taken into account. Since the presented analysis was from the perspective of the different stakeholders involved in the governance of Schiphol's long-term development, however, costs are less of an issue than if the analysis were carried out from a business perspective. Costs in the presented case would be only one among the six performance indicators. Furthermore, in those situations in which the new runway was part of the Master Plan but was not necessary, the adaptive plan would likely have saved expenses, while in those cases in which a trigger for building the runway would have been reached, the cost difference between the adaptive plan and the Master Plan would have been small. These two considerations together imply that including costs in the analysis would have made the adaptive plan look better in those situations in which the new runway would not be necessary, while in those situations in which it would be necessary, it would fail to differentiate between the plans. Adding cost to the analysis, therefore, would not alter the conclusions reached about the efficacy of AASP.

Third, in addition to costs, many other performance metrics are also relevant to long term airport planning. For example, the results reported on in this paper do not cover metrics related to terminal performance. Expanding the model to also cover other important areas of concern to airport planners and operators is thus required. Of particular interest here are expansions aimed at including the terminal and its capacity and delay, and airside delays.

CONCLUSIONS AND RECOMMENDATIONS

Airports around the world operate in an increasingly uncertain environment. An airline is able to change its network structure overnight. The oil price, flu epidemics, and financial and economic woes further add to the volatility of aviation demand development. These uncertainties, combined with tensions between economic and environmental impacts, make airport strategic planning a challenging task. The current approach to airport strategic planning is Master Planning. This approach is based on forecasting future demand and then drafting a static blueprint for accommodating this demand. It has been recognized in the literature that an alternative to this approach is called for, since AMP produces undesirable consequences, such as over investment in capacity or being too late in increasing capacity. A variety of alternative approaches have been put forward by different authors. All these approaches share an emphasis on flexibility and adaptability as the appropriate way for dealing with uncertainty. Recently, a synthesis of the different ideas has been put forward called Adaptive Airport Strategic Planning.

Before new planning approaches are applied in practice, evidence needs to be provided about their efficacy. In establishing the efficacy of new infrastructure planning approaches, one faces a methodological problem, for ”nothing done in the short term can ‘prove’ the efficacy of a planning methodology; nor can the monitoring, over time, of a single instance of a plan generated by that methodology, unless there is a competing parallel plan” (Dewar et al., 1993). By adapting an approach similar to the one used in the medical sciences for assessing the efficacy of new treatments, this methodological problem can be overcome. An important element in the approach in medicine is the use of animal models. Animal models, or computational models in case of infrastructure planning, allow the performance of competing plans to be compared across a wide variety of plausible future developments.

By assessing the performance of a Master Plan and an adaptive plan across a wide range of plausible developments, evidence can be generated about the efficacy of AASP. Using Exploratory Modeling and Analysis (EMA), we explored the performance of a Master Plan and an adaptive plan across a large space of uncertainties for the case of Amsterdam Airport Schiphol. This is a relatively large airport that operates in a privatized and liberalized market. The strategic planning problems Schiphol faces are arguably comparable to the problems faced by other large airports around the world. As such, it is a good test case for assessing the efficacy of AASP. The EMA analysis revealed that given the same ranges of uncertainties as inputs, an adaptive plan has less variance in its outcomes then a Master Plan. Thus, an adaptive plan exposes an airport to less risk than a Master Plan. Furthermore, the decrease in downside risk does not significantly affect the upside potential. Taken together, this strongly suggests that AASP is an effective approach to ASP. Airports should seriously consider using such adaptive approaches in their future long-term planning.

The evidence we have provided for the efficacy of AASP is a first source of evidence. However, there are a variety of questions, mainly related to the behavior of the stakeholders responsible for governing airport development, still open. The main research challenge, therefore, specifically for AASP, but also in general for approaches and techniques belonging to the adaptive paradigm, appears to be about the institutional arrangements that are necessary for adaptive plans to be implemented. Addressing this issue will be of crucial importance for the success or failure of adaptive planning approaches.

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