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, 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 static Master Plan. So, the Adaptive Plan will expose an airport less to negative outcomes. Furthermore, in those cases in which the Master Plan produces preferable outcomes, the difference in performance compared to the Adaptive Plan is rather small. Moreover, AMP is better than AASP for only a small range of future conditions. These three findings together suggest that AASP minimizes the downside risk without significantly reducing the upside potential. As such, the findings suggest that AASP should be preferred to AMP for airport strategic planning.

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

1.1 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 (Burghouwt, 2007; de Neufville, 2000; Kwakkel, Walker, & Marchau, 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 (Burghouwt, 2007; de Neufville, 2000; Kwakkel, et al., in press).

The efficacy of alternatives to AMP needs to be established before any alternative is used in practice. However, the validity and efficacy of such new infrastructure planning approaches has not been explored in depth (Hansman, Magee, De Neufville, Robins, & Roos, 2006; Marchau, Walker, & van Duin, 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, Builder, Hix, & Levin, 1993; Hansman, et al., 2006). We will argue that computational experiments using Exploratory Modeling and Analysis (Bankes, 1993) — an operations research technique — 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 static 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.

1.2 Handling Uncertainty in Airport Strategic Planning

1.2.1 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 a plan and not on the decisionmaking process about the plan. Admittedly, the decisionmaking process is interwoven with AMP, but for analysis purposes we focus here on AMP. The role of the decisionmaking process in AMP has been extensively studied (e.g Dempsey, Goetz, & Szyliowicz, 1997; van Eeten, 1998). For other transport planning cases, see for example the work of Flyvberg et al. (e.g Flyvbjerg, 2005; Flyvbjerg, Bruzelius, & Rothengatter, 2003). 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 (de Neufville & Odoni, 2003; IATA, 2004; ICAO, 1987).

The goal of Master Planning is to provide a blueprint that will determine the future development of the airport (Burghouwt & Huys, 2003; Dempsey, et al., 1997). 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 plan 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 (Szyliowicz and Goetz, 1995, Cidell, 2004, Kwakkel et al., 2007, Dempsey et al., 1997, Nelkin, 1975, Nelkin, 1974). This inefficacy of AMP is well recognized in the literature (e.g. Burghouwt, 2007; Burghouwt & Huys, 2003; de Neufville, 1991, 2000, 2003; de Neufville & Barber, 1991; de Neufville & Odoni, 2003; Kwakkel, et al., in press).

There are two main reasons for the inefficacy of AMP; 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; Flyvbjerg, 2005; Porter, Roper, Mason, Rossini, & Banks, 1991). 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, a Master Plan has a blueprint character (Burghouwt & Huys, 2003). It presents a construction plan that envisions the maximum development of the airport and guides the capital investments in its facilities (Kazda & Caves, 2000). As such, it generally does not consider changing conditions or conditions significantly different from those presented by the forecast. Consequently, the Master Plan leaves little room for adapting to changing conditions during the implementation phase. The inability to forecast future demand with sufficient precision and the static character of Master Plans together render AMP problematic for ASP.

In practice, airport planners try to deal with the inefficacy of AMP in various ways. There are (formal) procedures in place for updating the Master Plan; since the Master Plan often consists of a list of semi-independent capital investment projects, there is some room to postpone or speed up projects. Sometimes, it is also possible to solve problems that emerge when the real world deviates significantly from the anticipated world underlying the Master Plan by making operational adjustments. For example, the Australian Airport Act specifies that the Master Plan needs to be formally updated every five years. In this way, stepwise adaptation to changing conditions is realized. Despite the well known problems surrounding the development of the Denver Airport, Dempsey et al. (1997) praise the technical design of the airport for its modular character, which allows for the gradual development of the airport facilities depending on how the actual conditions evolve. Operational procedures at Schiphol were implemented that allow for the use of one of the finger piers for both Schengen and non-Schengen passengers. By changing the setting of certain doors, passengers are guided to immigration or not. This allows the airport to adapt to changing patterns of demand. Still, the ways in which airport planners cope with uncertainty and find creative workarounds mainly operate within the confines of a static Master Planning approach based on a limited appreciation for the multiplicity of futures. As explained in more detail in Sections 3 and 4, the computational experiments reported on do not take these types of adaptations of the Master Plan into account. So, our experiments present the best case for the alternative approaches to AMP.

1.2.2 Adaptive Airport Strategic Planning

In response to the problematic nature of AMP, a number of alternatives have emerged (Burghouwt, 2007; e.g. de Neufville, 2000; Kwakkel, Walker, & Marchau, 2007). Recently, a synthesis of these alternatives, 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 planning framework (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 & 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 non-regret time-urgent actions. So, an Adaptive Plan consists of a set of actions to be taken immediately and a framework for future actions that specifies under what conditions these actions will be taken.

Although a generic approach to policymaking, the main area of research on adaptive plans has been in strategic planning for transport systems (Agusdinata, Marchau, & Walker, 2007; Kwakkel, et al., 2007; Marchau & Walker, 2003; Marchau, et al., 2009). AASP is a syntheses 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 III: mitigating actions are actions to reduce the *certain* adverse effects of a plan; hedging actions are actions to spread or reduce the risk of *uncertain* adverse effects of a plan; seizing actions are actions taken to seize certain available opportunities; and 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: 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; corrective actions are adjustments to the basic plan; capitalizing actions are actions trigger to take advantage of opportunities that improve the performance of the basic plan; and a reassessment of the plan is initiated when the analysis and assumptions critical to the plan's success have clearly lost validity. Step V is the actual implementation. In this step, the actions to be taken immediately (from Step II and Step III) are implemented and a monitoring system (from Step IV) is established. Then time starts running, signpost information related to the triggers is collected, and actions are started, altered, stopped, or expanded in response to this information. After implementation of the initial actions, the implementation of other actions is suspended until a trigger event occurs. The central claim of APM is that a more successful coherent development of infrastructure can be achieved by planning for adaptation instead of having to make ad-hoc adaptations and modifications to existing plans For a more detailed explanation of this framework, see Kwakkel et al (in press), Marchau et al. (2009), and Walker et al. (2001).

<FIGURE 1 SHOULD GO HERE>

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

Discussions on adaptivity and flexibility in the airport planning literature have mainly been theoretical. Limited attention is given to how airports are already trying to address the problems uncertainty poses to ASP. It is conceivable that the way in which AMP is implemented and applied at a given airport is very close to the principles and ideas of AASP. However, there is nothing inherent in AMP to guarantee this. If an airport's plan is based on a limited appreciation of the multiplicity of futures and not designed with flexibility and adaptability in mind, in this paper we call it AMP. Conversely, if the plan explicitly addresses the multiplicity of plausible futures and explicitly makes use of concepts such as adaptability and flexibility, we would consider it a form of AASP. In actual practice, these distinctions might be matters of degree, rather than sharp distinctions. However, for a theoretical understanding, this conceptual clarity is desirable.

1.3 Method 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 & 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, 2009) Simulation gaming with students (Mayer & Veeneman, 2002)
In Vitro Experiments	Simulation gaming with actual decisionmakers (Mayer & Veeneman, 2002)
Natural Experiments	Case studies of successful long-term infrastructure plans
Clinical Trials	Pilot projects (Vreugenhil, Slinger, Thissen, & Ker Rault, In Press)

With respect to assessing the efficacy of new planning approaches, two possible objects of study are: the set of analytic activies that are employed in developing a plan and the plan that emerges as a result from these activities (Thissen & Twaalfhoven, 2001). The criteria of evaluation differ accordingly. With respect to the set of activities, relevant criteria include e.g., the appropriateness of the subject on which the analysis was focused, the validity of the analysis methods used, and the variety of alternatives and criteria that were considered in the analysis, the transparency of the organization of the analysis process, the cooperation among and/or involvement of various parties, the internal and external communication during the activities, and the use of resources, time and money (Thissen & Twaalfhoven, 2001). With regard to the plan, the criteria focus on evaluating the effects of the plan, such as what is the range of expected outcomes, under what conditions would a traditional plan outperform an Adaptive Plan, and under what conditions would an Adaptive Plan outperform a traditional plan. This paper focuses on the relative performance of the plans.

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 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. The use of computational experiments allows for the comparison of two competing instances of a plan across a wide range of plausible conditions, overcoming the previously mentioned methodological problem highlighted by Dewar (1993).

EMA is a research methodology to analyze complex and uncertain systems (Agusdinata, 2008; Bankes, 1993). It can be contrasted with a *consolidative modeling* approach, in which all the existing knowledge about a system is consolidated in a model that is subsequently used as a surrogate for the real world system (Hodges, 1991; Hodges & Dewar, 1992). The consolidative 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 (Marchau et al., 2009, Van Geenhuizen et al., 2007, Dewar and Wachs, 2006). 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. 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 (Agusdinata, 2008; Bankes, 1993). EMA thus does not intend to forecast or predict what will happen, but aims to explore what could happen under the stated assumptions. Quantitative results from EMA should be interpreted accordingly. Similar to methodologies for content analysis and text mining, EMA is a rigorous quantitative methodology that produces primarily qualitative insights. 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, 2009; Bankes, Lempert, & Popper, 2002). 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 generated by 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.

1.4 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. A next step in assessing the efficacy of AASP with respect to the plan that emerges from it, is to quantitatively explore the difference in performance between a traditional Master Plan and an Adaptive Plan across a large ensemble of futures through EMA. Through a series of computational experiments, insight can be gained into if and when each plan would perform better.

1.4.1 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, Walker, & Wijnen, 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 airport. 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 both air transport movements and passenger movements (Schiphol Group, 2010). The merger of Air France and KLM has resulted in the threat that KLM, Schiphol's hub carrier, which is responsible for the majority 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 capacity or are developing dual airport systems. Together, this makes the long-term planning for Schiphol both urgent and problematic.

1.4.2 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. In this specific case, we choose to have a variety of *generators*, while we use a single model for calculating airport performance. 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 developments. Figure **Error! No text of specified style in document.**-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 SHOULD GO HERE>

Figure Error! No text of specified style in document.**-2: Conceptual design of the model**

Airport performance analysis component

The airport performance analysis component is based on the Fast and Simple Model for Airport Performance Analysis (FASMAPA)(Kwakkel, Wijnen, Walker, & Marchau, 2009). In essence, FASMAPA is the computational core of the HARMOS decision support system for Airport Strategic Planning (Heblij & Wijnen, 2008; R. A. A. Wijnen, Visser, & Walker, 2009; R.A.A. Wijnen, Walker, & Kwakkel, 2008), with the exception that a different model is used for calculating noise. 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. This fits 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 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. The selection of tools is motivated by the purpose of FASMAPA: to allow for a strategic quick scan of the performance of alternative plans. Macroscopic tools have therefore been used (de Neufville & Odoni, 2003; Stamatopoulos, Zografos, & Odoni, 2004). Table 2 specifies the tools that are used. 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 Aspect	**Tool**
Capacity	FAA Airfield Capacity Model (FCM) − an extension of the classic Blumstein model (Agusdinata, 2008; de Neufville & Odoni, 2003; FAA, 1981). It is a macroscopic tool for estimating the maximum hourly throughput capacity of the runway system and final approach. It does not consider aprons, taxiways, and the terminal area airspace.
Noise	Area Equivalent Method (AEM)– a model that approximates Integrated Noise Model (INM) results (FAA, 2008). Compared to INM, AEM does not consider flight paths. Other than this, the way of calculating the size of noise contours is the same.
Emissions	Emission Dispersion Modeling System (EDMS) − the FAA required tool for emission analysis (FAA, 2009), EDMS consists of an emissions inventory system that calculates the sum of emissions from various sources including aircrafts, Auxiliary Power Units, roadways etc. It also contains a components for dispersion analysis, taking weather etc. into account. FASMAPA only covers the emission inventory part.
Third Party Risk	Methodology developed by the National Air Traffic Services (NATS) for third-party risk (Cowell, et al., 2000; Cowell, Gerrard, & Paterson, 1997) − the NATS methodology has been extended to apply to multiple runways (Heblij, 2004, Heblij and Wijnen, 2008). The NATS methodology calculates the probability and effect of a crash for a given location relative to a runway in light of historical data about the crash frequency for different aircraft categories and the different parts of the landing take-off cycle.

The generators

FASMAPA focuses on calculating 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, Popper, & Bankes, 2003). This scenario generator allows for generating demand volumes, wind conditions, technological developments, and changes in demographic patterns around the airport. With respect to the different generators that make up the scenario generator, each of them uses different structural assumptions. Table 3 summarizes the uncertainties that can be explored with FASMAPA and the scenario generator. Where information on the ranges was available, the source is given. The remainder reflect numbers encountered in various policy documents and expert opinions, which are deemed plausible. Analogously to scenario planning, what is important in EMA is not to provide detailed predictions of what will happen, but to use ranges that are plausible.

Table 3: Overview of the uncertainties

Types of Uncertainties	Variations Examined
Model structure uncertainties	
Demand	– Exponential growth – Logistic growth – Logistic growth followed by logistic decline
Long-haul vs. Short-haul aircraft mix	– Linear change in ratio of long haul – Logistic change in ratio of long haul
Population	– Logistic growth – Logistic growth to a maximum followed by logistic decline
ATM technology	– Exponential performance increase – logistic performance increase
Engine technology (noise/emissions)	– Exponential performance increase – logistic performance increase
Parameterization of structural uncertainties	
Exponential demand growth	Ratio over 30 years, range:1-1.06: this corresponds to 0% growth in air transport movements per year and 6% growth in air transport movements per year
Logistic demand growth	Demand over 30 years, range: 390000-800000 air transport movements
Logistic demand growth, followed by logistic decline	– Demand over 30 years, range: 250000-375000 air transport movements – Year in which maximum will be reached, range: 2012-2020 – Demand in year of maximum, range: 400000-435000 air transport movements
Linear change in long-haul ratio (De Haan, 2007)	Ratio of long haul, range: 0.05-0.5; this corresponds to 5% and 50% long-haul air transport movements respectively
Logistic change in long-haul ratio (De Haan, 2007)	Ratio of long haul, range: 0.05-0.5; this corresponds to 5% and 50% long-haul air transport movements respectively
Logistic population growth (de Jong & Hilderdink, 2004)	Population size in 30 year, range: 17-20 million people
Logistic population growth to max followed by decline (de Jong & Hilderdink, 2004)	– Population size in 30 year, range:12-16 million people – Population size at maximum, range: 16-17 million people – Year maximum will be reached, range: 2010-2020
Exponential ATM technology development	ATM technology improvement in 30 years, range: 0.85-1, this implies a reduction in separation standards of 15% and 0% respectively
Logistic ATM technology development	ATM technology improvement in 30 years, range:

	0.85-1, this implies a reduction in separation standards of 15% and 0% respectively
Exponential engine technology development (De Haan, 2007)	Engine technology improvement technology improvement over 30 years, range: 0.65-1; this implies a reduction in emissions of between 45% and 0% respectively
Logistic engine technology development (De Haan, 2007)	Engine technology improvement technology improvement over 30 years, range: 0.65-1; this implies a reduction in emissions of between 45% and 0% respectively
Parametric uncertainties	
Weather (KNMI, 2006)	Percentage of change in days with severe wind conditions per year, range: -1% - +4%; this implies between 1% increase and 4% decrease of availability of affected runway configurations.

1.4.3 The Master Plan and the Adaptive Plan

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, KiM, NMP, & RP, 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 & LVNL, 2007). There are several types of changes that are currently being considered by the governance network in order to achieve these goals. The physical capacity can be expanded by using its existing runways and terminals more efficiently and/or building new capacity. More explicitly, among the options that are considered:

1. Add a new runway parallel to one of the existing runways
2. Move charter operations out of Schiphol (i.e., to Lelystad and Eindhoven, which have a planned capacity of roughly 70,000 operations per year (Rijksoverheid, 2009; Schiphol Group, 2007))
3. 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 4. The contingency plan is outlined in Table 5. 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 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 4: Increasing the robustness of the basic plan

Vulnerabilities and Opportunities	Hedging (H) and Shaping (SH) Actions
Demand for air traffic grows faster than forecast.	**H**: Prepare Lelystad and Eindhoven airport to receive charter flights
Increase in the population density in 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
Maintain current trend of decrease of environmental impact of aircraft	**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
Development of wind conditions due to climate change	**H:** Have plans ready to quickly build the sixth runway, but do not build it yet. If wind conditions deteriorate even further, start construction

Table 5: 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 traffic grows faster than forecast.	Monitor the growth of Schiphol in terms of aircraft movements. If this exceeds 450.000 operations, start building the new runway. 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.	**CP:** Begin to implement the plan for the new runway **CR**: Move a portion of the operations to Lelystad and Eindhoven. **RE**: Reassess entire plan
Increase area affected by noise	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.
Development of wind conditions 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.

In this comparison, we focus on comparing the performance of the plans. We assume that the plans are executed as written. Uncertainties regarding the implementation are not taken into account. As discussed above, in practice airport planners under a Master Planning regime do sometimes defer or speed up aspects of the Master Plan, implement (formal) updates to the Master Plans, and try and use operational changes to accommodate the divergence between forecasted and real world circumstances. This behavior is not included in the comparison. These types of adaptations to the Master Plan that can occur in practice will reduce the difference in performance between the Master Plan and the Adaptive Plan. So our comparison of the two provides an indication of the best case for the Adaptive Plan. In short, the comparison focuses on the theoretical differences between a static Master Plan and a dynamic Adaptive Plan. We return to this point in Section 1.5.

1.4.4 Results

There are two specific questions we answer in this section:

- Question 1: given the ranges of uncertainties and the different models, what is the range of outcomes that both the Master Plan and the Adaptive Plan can generate? If the Adaptive Plan is any good, its range of outcomes should be smaller; or, put differently, the risks associated with the Adaptive Plan should be smaller.
- Question 2:given the most favorable conditions for a Master Plan, how well does the Adaptive Plan do in comparison? This question is motivated by the idea that, if an Adaptive Plan is to be attractive to decisionmakers, it should perform about equal to a Master Plan or better, even under those conditions that most favor the Master Plan.

As outcome indicators, we used LDN (a metric for averaging day and night flights by penalizing night flights) for noise, 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 as a proxy for environmental impacts. LDN and ACE are well established metrics. Similarly, PANCAP is a high level metric for a quick assessment of capacity on a yearly basis. Ideally, insight into delays should also be given, however the FCM tool does not generate this. To create some high level insight into the ratio of capacity and demand, we calculate the PANCAP – accommodated demand ratio. This is defined as the minimum of the maximum annual throughput capacity given opening hours of the airport and the demand, divided by the PANCAP. If demand is higher than the maximum annual throughput capacity, this portion of the demand will not be accommodated and becomes part of the latent demand. Admittedly, this ratio is a rough proxy for delays, but given that the presented comparison is at a strategic level, overly detailed models are inappropriate (Stamatopoulos, et al., 2004). Such detailed calculations only create a false sense of precision, since their true values are overwhelmed by the uncertainties. Moreover, if a more detailed delay analysis were included, additional assumptions with respect to among others the distribution of planned flights over the day, the deviation between actual and scheduled arrivals and departures, and the distribution of flights over the year would be needed. The choice for CO as a proxy for overall environmental impacts is motivated by the available data (the ICAO engine emissions data bank) pertaining to the emissions of the various engines during the respective parts of the Landing Take Off (LTO) cycle. This databank only has data for NO_x, CO, SO^2, and VOC.

Question 1 above reduces to solving a boundary problem. For each outcome of interest, the upper and lower bound across both the model structures and parametric uncertainties needs to be determined. Technically, this requires the use of a non-linear optimization algorithm. For each outcome of interest, across each model structure and its parameter ranges, and across both plans, the minimum and maximum should be determined. To fully explore this would require 1344 separate optimizations, regardless of the problem of local versus global optima. However, these need not all be explored. For example, the lower bound on the cumulative CO-emissions will be found in that model structure that has the lowest number of flights. Similar arguments can be presented for the other outcomes, reducing the number of optimization problems significantly.. The results of the overall analysis are shown in Table 6. From this table, it can be concluded that an Adaptive Plan has a smaller bound on all outcome indicators except for 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. The high value of the PANCAP – accommodated demand ratio for the upper bound of the Master Plan is explained by the large discrepancy between maximum annual throughput capacity, which determines the maximum accommodated demand, and PANCAP. Such a high figure implies that the airport is heavily capacity constrained and is experiencing severe delays.

Table 6: Performance bounds of the Master Plan and the Adaptive Plan

Outcome indicators	**Lower Bound**		**Upper Bound**	
	Master Plan	**Adaptive Plan**	**Master Plan**	**Adaptive Plan**
Size of 65 LDN contour after thirty years (km^2)	13.2	10.2	63.8	47.4
Max. size of 65 LDN contour (km^2)	17.9	17.9	63.8	47.7
Cumulative ACE (ACE)	0.9	1.1	2.7	2.3
PANCAP - accommodated demand ratio after thirty years	0.25	0.89	2.48	1.1
Max PANCAP -	0.9	0.52	2.48	1.1

accommodated demand ratio				
Accumulated latent demand (flights)	0	0	5,058,504	8,290,622
Cumulative CO emission (kg)	21,520.9	19,773.9	195,729.1	103,899.5

In order to identify the difference in performance between an Adaptive Plan and a Master Plan, we follow an approach similar to Agusdinata (2008) and Lempert et al. (2003). First, we identify the combination of uncertain parameters under which the Master Plan performs the best compared with the Adaptive Plan. So, we try to find the best case for the Master Plan compared with the Adaptive Plan. Once this point is identified, all uncertain parameters apart from demand growth and the long-haul ratio are fixed to their values at this point. The choice for demand growth and long-haul ratio is motivated by the observation that the main uncertainties in ASP are about the size and composition of future demand (Burghouwt, 2007; de Neufville & Odoni, 2003). A full factorial design is generated for the long-haul ratio and demand growth per year, with 21 samples for each, resulting in 441 cases. For each case, the performance difference is calculated.

In order to determine the performance difference, we use ACE, PANCAP - accommodated demand ratio, latent demand, size of the 65 LDN contour, and cumulative CO emissions as outcome indicators. Next, these indicators are normalized, using the maxima and minima from Table 6 so that they scale between 0 (bad) and 1 (good). That is, the actual outcomes are mapped to a unit interval in order to make them comparable. So, for example the maximum size of the noise contour (63.8 km^2) is mapped to 0, and the minimum size of the noise contour (10.2 km^2) is mapped to 1. The five normalized outcome 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. The performance difference between the two plans then becomes the difference in length between the performance vector of the Master Plan and the performance vector of the Adaptive Plan.

The resulting performance differences are shown in Figure **Error! No text of specified style in document.**-3 Grayscale is used to indicate the value of the performance difference. If this value is below 0, the Master Plan is 'better' than the Adaptive Plan. From this figure, we conclude that even under the conditions that *most* favor the Master Plan, the Master Plan is only slightly better than the Adaptive Plan. Furthermore, the Master Plan is better only in a relatively small area. So, if the long-haul ratio and/or the demand growth deviate slightly from those that are the best for the Master Plan, the Master Plan will perform worse than the Adaptive Plan.

<FIGURE 3 SHOULD GO HERE>

Figure Error! No text of specified style in document.**-3: Performance difference of the Adaptive Plan compared to the Master Plan for that combination of uncertain parameters that most favor the Master Plan**

Figure **Error! No text of specified style in document.**-4 shows the same type of analysis as Figure **Error! No text of specified style in document.**-3 with a single important difference. Here, the conditions that *most* favor the Adaptive Plan have first been identified. This figure has a structure very similar to Figure **Error! No text of specified style in document.**-3, suggesting that the other uncertainties have indeed only a minor influence on the performance of the plan. Furthermore, it shows again that the Master Plan performs slightly better than the Adaptive Plan only in a narrow bandwidth of demand growth.

<FIGURE 4 SHOULD GO HERE>

Figure Error! No text of specified style in document.**-4: Performance difference of the Adaptive Plan compared to the Master Plan for that combination of uncertain parameters that most favor the Adaptive Plan**

Figure **Error! No text of specified style in document.**-3 and Figure **Error! No text of specified style in document.**-4 cover only growing demand. However, these figures do suggest that if demand were to decline, the Adaptive Plan would also be preferable. This makes sense since, in those cases, the new runway would not be built, resulting in double the utilization compared to the Master Plan (see also Table 6). To test this hypothesis, we looked at the model structure that covers declining demand and explored it using the same approach as used to generate Figure **Error! No text of specified style in document.**-3 and Figure **Error! No text of specified style in document.**-4. We did not find a single case in which the Master Plan would perform better then the Adaptive Plan.

As a final step, summarizing the foregoing analyses, we generated Figure **Error! No text of specified style in document.**-5 and Figure **Error! No text of specified style in document.**-6. For these figures, the values of all the uncertain parameters were fixed to the values at the point that is the most positive for the Master Plan. Next, for Figure **Error! No text of specified style in document.**-5, which covers growing demand, we varied the demand growth parameter between 1 and 1.06 with a step size of 0.001. The two extreme values of the range correspond to a zero percent increase and a six percent increase in aviation demand per year respectively. For Figure **Error! No text of specified style in document.**-6, which covers the case of declining demand, we varied the demand between 250000 and 375000 air transport movements in thirty years. The y-axis shows the performance difference, defined in the same way as in Figure **Error! No text of specified style in document.**-3 and Figure **Error! No text of specified style in document.**-4. Above 0 on the y-axis, the Adaptive Plan performs better. Below 0 on the y-axis, the Master Plan performs better. As is clear from these figures, the Master Plan performs better than the Adaptive Plan in only a very narrow range of demand growth. Only if the growth in demand is between roughly 0% and 2% per year will the Master Plan perform better. Based on Figures 6.4-6.66 and Table 6, we conclude that given even medium levels of uncertainty, the Adaptive Plan will perform better than the Master Plan. The results of these analyses thus corroborate the hypothesis that Adaptive Strategic Airport Planning is to be preferred over Master Planning.

<FIGURE 5 SHOULD GO HERE>

Figure Error! No text of specified style in document.**-5: Performance difference of the Adaptive Plan compared to the Master Plan for the situation most favorable to the Master Plan, with demand varied between 0% growth per year and 6% growth per year**

<FIGURE 6 SHOULD GO HERE>

Figure Error! No text of specified style in document.**-6: Performance difference of the Adaptive Plan compared to the Master Plan for the situation most favorable to the Master Plan, with demand varied between 250000 and 375000 air transport movements in thirty years**

1.5 Discussion

From the foregoing, we conclude that, for this case, Master Planning is preferable to Adaptive Planning only if the future demand were to fall into a narrow bandwidth. Conversely, if there is even small uncertainty about future demand, Adaptive Planning is to be preferred. 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. Hence, based on the computational experiments reported above, we conclude that, in privatized and liberalized aviation markets, AASP would be preferred to static Master Planning.

This does not mean that airport planners should immediately switch to AASP. First, as already discussed, ad hoc adaptive planning is used in practice. Parts of the Master Plan are deferred or sped up, operational changes are made, and, if necessary, formal updates to the Master Plan are submitted. Our experiments have not taken such ad hoc deviations from and (formal) updates to the Master Plan into account. There is merit to this argument. However, first and foremost, there is currently limited (computational) evidence for the efficacy of traditional planning approaches such as AMP as compared to innovative infrastructure planning approaches such as AASP. This paper provides such evidence for a theoretical case of a Master Plan and an Adaptive Plan. However, further research is needed to bring the case closer to real world practice, although it is not clear how to model the implementation phase of the Master Plan that gives rise to the unplanned ad hoc changes that are made in response to changing conditions. The modeling of the implementation phase will be critically dependent on the case. The formal and informal rules and institutions that are involved in the implementation phase differ from one airport to the next and from one country to another. One option would be to use some form of an agent based model to represent the various actors, rules, and institutions. Alternatively, or in addition, simulation gaming could be combined with computational experiments to reveal how the implementation process might evolve. This, in fact, is implied by the medical analogy introduced in Section 1.3. 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.

Apart from the argument that more and other sources of evidence are needed, one should also realize that the single biggest difference between AMP and AASP is that AASP explicitly takes uncertainty into account during the planning process and provides a plan that contains a framework for shaping and responding to a wide range of conceivable external conditions. In contrast, in AMP there is little planning for uncertainty developments, and the extent to which planners cope with changing conditions is totally dependent on the diligence and responsiveness of the involved planners. As such, there is no guarantee that AMP planners will adaptively respond to changing conditions. Moreover, the rigid planning approach that is prescribed for AMP arguably reduces the ability of the planners to adapt the plan compared to the situation that would occur under an AASP planning regime. So we concludate that further evidence is needed for the efficacy of AASP — specifically with respect to how different the performance is between a Master Plan as implemented in practice and AASP.

A second reason for not immediately switching to AASP is that we looked only at the case of Amsterdam Airport Schiphol. How generalizable are our findings? Schiphol is a relatively large airport in a privatized and liberalized market. Some of the uncertainties that the decisionmakers are facing are particular to that airport (e.g. wind conditions), but most others are faced by most large airports in the world (e.g. demand volatility, technological developments, and demographics). Given that the difference in airport performance is most sensitive to demand variations, we believe that the findings of this single case can be generalized to those airports that also operate in a privatized and liberalized environment.

Third, 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.

1.6 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 investments 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 range 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, an Adaptive Plan has less variance in its outcomes then a Master Plan. Thus, the Adaptive Plan exposes an airport to less risk than the Master Plan. Furthermore, we analyzed in more detail the conditions under which the Master Plan would be preferred over the Adaptive Plan. This analysis showed that even small demand variations would change the preference ordering. That is, if demand is slightly higher or lower than that which is optimal for a Master Plan, the Adaptive Plan would perform better. In addition, this second analysis showed that, if the Master Plan performs better, the performance difference is only small.

These two analyses taken together provide corroborating evidence for the efficacy of Adaptive Airport Strategic Planning. However, there are a variety of questions, mainly related to the actual implementation of Master Plans, still open. There are also questions related to the institutional arrangements that are necessary for Adaptive Plans to be implemented. Addressing these questions will be of crucial importance for the success or failure of Adaptive Planning approaches.

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