PORTFOLIO ANALYSIS OF AIR TRANSPORTATION INFRASTRACTURE INVESTMENT

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Abstract

The air transportation system is a significant "engine" of the national economy providing cost-effective transportation of goods and services. This form of transportation is heavily reliant on a large, distributed, and capital-intensive infrastructure that must be maintained and enhanced in a timely manner to ensure a reliable transport service. Researchers have shown that the national air transportation infrastructure must be enhanced to meet the growing demand.

This paper describes the results of an analysis of alternative investment strategies for increasing the capacity of the National Airspace System (NAS). The dynamic system analysis shows that there exists a tradeoff between the cost of any unutilized capacity that is added, and the cost of congestion not addressed by additional capacity. Table 1 shows the trade-space for decision makes to choose the optimum investment given their risk acceptance and the start time of the capacity project. Net Present Value (NPV) is maximized for risk-averse decision makers when capacity is increased moderately (25%) with lead-times less than 5 years.

1. Introduction

The air transportation system provides for the cost-effective transportation of goods and services, and a significant "engine" of the economy. About 75% of long distance and 42% of medium distance travelers prefer air travel (*1*). The air transportation industry requires large capital investments in order to provide services. Amongst capital investments, airport capacity comes up as one of the most significant issues facing civil aviation since building new airports can be more expensive than expanding available facilities (*1*). Moreover, policy makers have to rely on tools to project the impacts of their policies in the presence of long lead-times. (*2*).

This paper describes the results of an analysis of alternative investment strategies for increasing the capacity of the NAS. The major results of the analysis are as follows:

1. There exists a tradeoff between the cost of any unutilized capacity that is added, and the cost of congestion not addressed by additional capacity.
2. Net Present Value (NPV) is maximized for risk-averse decision makers when capacity is increased moderately (10%-25%) with lead-times less than 5 years.

This paper is organized as follows; Section 2 provides background and previous research, Section 3 describes the methodology used in this study. Section 4 includes results, and Section 5 provides some conclusions.

2. Background

Analysis of infrastructure improvement in transportation is a widely studied phenomenon (*3, 4, 5*). Due to the interactive nature of transportation on the economy and the impact of demand on capacity, Dynamic System Models have been widely used.

PAMELA is a wide-scope, top-level model developed by EUROCONTROL that simulates the main components of supply for air traffic services over the long-term using system dynamics. It models the period 2000-2020 in 34 European Civil Aviation Conference countries. It performs regional level analysis as well as national and system level whenever resources are shared. There are three interrelated domains in the model; 1. Recruitment, 2. Sector and Centre Capacity, and 3. Delay Performance. The capacity enhancement comes from either opening new sectors or training new controllers. The number of sectors added depends on the delays and the minimum sector transit time allowed. The number of controllers added depends on the delays and the recruitment strategy. However, the air traffic controllers hired today only become effective with a time lag due to training. These two supply factors determine the delay performance and costs incurred. As delays go down, recruitment is stopped since it becomes less urgent, in turn leading to decreases in capacity and new increase in delays. The demand for air traffic services and airport capacity are exogenous factors in the model (*6*).

The results of the model show that capacity improvements take time and proactive strategies yield better results for costs and delays in the system.

ASTRA (Assessment of Transport Strategies) is a dynamic system model developed to assess the long-term impacts of the European transport and economic policy with respect to economic, environmental and social effects. It covers 15 European Union countries and their neighbors. The model has 8 modules: 1.Population, 2.Macroeconomics, 3.Regional Economics, 4.Foreign Trade, 5.Transport, 6.Environment, 7.Vehicle Fleet, 8.Welfare Measurement. The main output of the model is Gross Domestic Product (GDP) for each simulated country (*2*).

The preliminary results of the model based on policy and infrastructure investment scenarios impact GDP of each country with different time lags. In turn, the changes in GDP feedback into other variables, such as income and exports, with the same lag. The results of the ASTRA-Italia model, smaller version of the model built for Italy, show that amongst three policy scenarios with different use of resources, the external costs are mainly determined by the characteristics of the overall system, and policies only add or subtract a small amount. The results also show that when travel becomes less expensive, longer trips become more frequent, congestion is increased thus making traveling more expansive (*7*).

Miler & Clarke (2003) developed a dynamic system model to evaluate different strategies for infrastructure deliveries in air transportation. It models delivery strategies using three variables: the amount of capacity increase, the time to deliver capacity, and the congestion threshold that triggers the need for capacity delivery. It calculates the difference between the NPV of a chosen strategy and that of a baseline strategy as a means to calculate the additional benefits of that strategy. The model assumes the runway capacity as the limiting factor for air transportation that leads to congestion. The model has three feedback loops: 1.Congestion cost, 2. Pax comfort, and 3. Capacity. The congestion cost loop models how if runway capacity is held constant, the increase in demand leads to congestion, which in turn raises the direct operating costs of airlines. Then, airlines pass these costs on to passengers in terms of higher airfares reducing demand for air travel. The pax comfort loop models how congestion also leads to less demand by increasing travel time. The capacity loop models how when congestion reaches a certain limit, more capacity is added to increase demand. How much capacity is added and when it is added depends on the delivery strategy chosen. The model uses Monte Carlo simulation to account for multiple sources of uncertainty (*8*).

The results of the model illustrate how a capacity delivery strategy based on small increments and short response times can yield more benefits than strategies with large capacity increase and long response times. The strategic value of reacting quickly increases if there is a moderate cost reduction in the delivery costs. Furthermore, the choice of discount rate is critical importance for infrastructure decisions.

3. Method

A deterministic dynamic system model is built to evaluate the investment strategies for air transportation infrastructure including revenues, costs and NPV. The model was baselined on Miller & Clarke (2003). The additional features in this model are described in Section 3.2.This model is run in a Monte Carlo simulation to evaluate the effects of the three strategic parameters:

1. When to Increase Capacity
2. How Much to Increase Capacity
3. Years to Increase Capacity

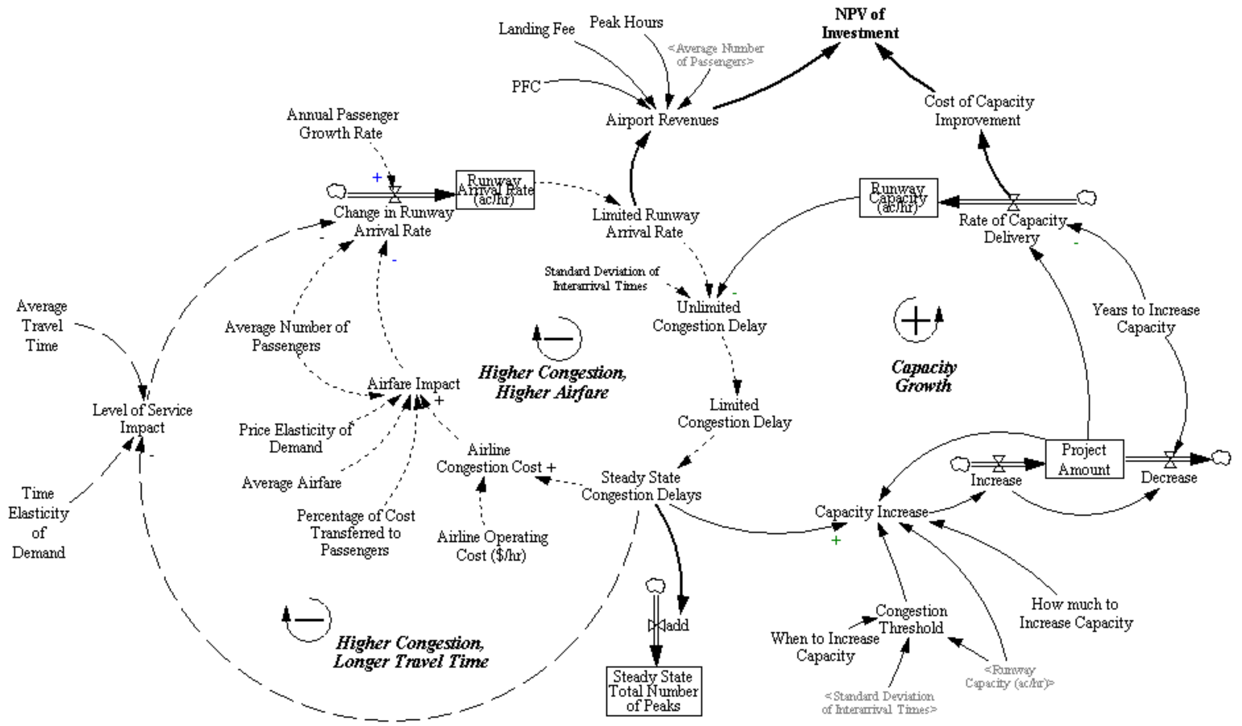
There are 36 scenarios investigated for this portfolio analysis. The amount of simulation runs for each scenario is determined using Optimal Computational Budget Allocation (OCBA) technique. The names of the variables used in the model are capitalized throughout the paper.

3.1 Deterministic Dynamic System Model for Air Transportation Infrastructure

Figure 1 shows the dynamic systems model built for evaluating air transportation infrastructure strategies. These strategies are represented by three variables, “When to Increase Capacity”, “How Much to Increase Capacity”, and “Years to Increase Capacity”. Each combination of these variables represents an investment strategy that result in different net present values (NPV) depending on how three feedback loops in the model react with each other.

The main output of the model is “NPV of Investment” (see upper right). It calculates how much value the chosen investment strategy will result in over the next 50 years. NPV of Investment is calculated by discounting the difference between Airport Revenues (cash inflows) and Cost of Capacity Improvement (cash outflows) per year. The more positive the NPV, the more value the strategy brings. A discount rate of 10% is used to adjust for time and risk taken.

FIGURE 1 Dynamic System Model for Air Transportation Infrastructure.



Airport Revenues are the revenues made from airport operations, which consist of Passenger Facilities Charge and Landing Fee. Airports in U.S. may impose a fee of $1 to $4.5 on enplaning passengers called Passenger Facilities Charge (PFC). It is collected by the airlines and travel agents at the time of ticket issuance and used by airports to fund FAA-approved airport improvement projects. PFC of $4.50 is selected to investigate the best possible value from the infrastructure investments. On the other hand, landing fees are paid by the airlines to the airport for each landing to be used on the maintenance or expansion of that airport's infrastructure. Landing fees can vary greatly between airports due to high demand for that specific landing slot and it is assumed to be $200 per aircraft. Thus, Airport Revenues are proportional to the number of aircraft that land at the airport and the number of passengers each aircraft carry. It is assumed that only narrow-body aircraft is operated (average seating capacity of 110) and congestion delays occur only at a given number of peak hours per year (1,000 hrs/year).

Cost of Capacity Improvement is the cost associated with capacity improvements completed each year. It is assumed that it costs $5 million for each enhancement that improves the runway arrival rate one aircraft per hour. Rate of Capacity Delivery is the amount of additional capacity delivered that year by the current infrastructure project. Then, Cost of Capacity Improvement is merely the multiplication of these two variables.

There are three feedback loops modeling the underlying behavior in the system. The right side of Figure 1 illustrates the supply side whereas the left side illustrates the demand side. "Capacity Growth" loop represents the supply side and shows how the capacity enhancement decisions are done. Both "Higher Congestion, Higher Airfare" and "Higher Congestion, Longer Travel Time" loops represent the demand side and show how these capacity decisions affect demand and thus future decisions about capacity improvements.

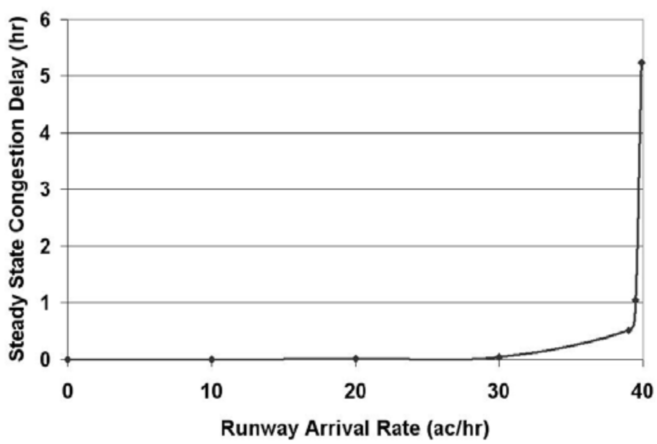
Higher Congestion, Higher Airfare This loop illustrates how an increase in congestion delays results in a decrease in airport demand due to higher airfares (small dotted lines in Figure 1).

Airport is modeled as a single runway with M/G/1 queuing system. The capacity of the airport is defined as the number of aircraft that can land on the runway in an hour and it is called "Runway Capacity". The demand for the airport is called "Runway Arrival Rate" and it is the number of aircraft that wants to land on the runway in an hour. However, Runway Arrival Rate can be negative if Change in Runway Arrival Rate is greater than Annual Passenger Growth Rate (demand loops together have more impact than the yearly growth rate) or if Annual Passenger Growth Rate is zero. Therefore, this value is limited to only positive values and is called "Limited Runway Arrival Rate". Then, Unlimited Congestion Delay is the waiting time for each aircraft that wants to land at the airport, and it is a function of Runway Capacity and Limited Runway Arrival Rate.

In M/G/1 queuing system, even if the mean service times stay unchanged, a decrease in the variability of service times can substantially reduce the customer waiting time. Standard Deviation of Interarrival Times captures this phenomenon and is assumed to be 20 seconds.

M/G/1 queuing system assumes that runway demand never exceeds runway capacity for the airport to operate in steady state. If Runway Capacity is held constant, increasing Runway Arrival Rate increases congestion delays as shown in Figure 2. However, sometimes runway demand is actually greater than the capacity during busy periods. This means that there are more aircraft waiting in queue than the capacity could serve and the waiting time for the aircraft goes to infinity. Since infinite delays for an aircraft is unrealistic, the model caps the delays at 18 hours (the number of hours in an operating day) and this capped delay is called "Steady State Congestion Delays".

FIGURE 2 Relationship between Congestion Delay and Runway Arrival Rate.



When Steady State Congestion Delays reach its maximum value (18 hours), this is critical for the airport. It shows that there are more airplanes that want to serve the airport than the airport can physically handle, resulting in congestion. Additional financial resources are required now to solve the congestion problem at the airport, which was not included in the current strategy when originally planned. Furthermore, the current infrastructure investment strategy is not working since the airport is losing the opportunity for growth by not satisfying the current demand. Therefore, the model counts the number of times Steady State Congestion

Delays reaches 18 hours over the next 50 years as another performance measure for the chosen investment strategy. This parameter is called “Steady State Total Number of Peaks”.

The congestion delays at the airport result in additional cost for the airlines. Airline Congestion Cost is the amount of additional direct operating costs airlines have to incur due to delays at the airport and it is directly proportional to the number of hours each aircraft is delayed as a result of congestion.

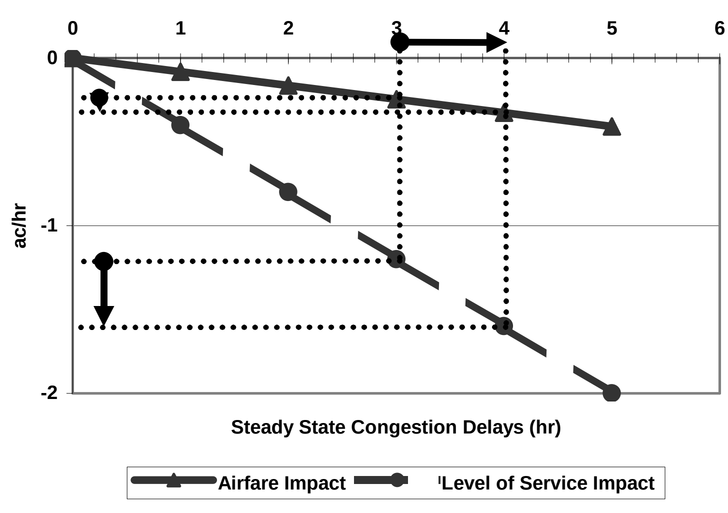
As a profit maximizing entity, airlines try to pass these higher additional costs on to the passengers in terms of higher airfares. However, this leads to less demand for both airlines and the airport due to price elasticity of passengers. Airfare Impact shows how much the runway demand changes due to changes in average airfare. It is a function of three parameters:

1. The price elasticity of demand. It is defined as the percentage change in passenger demand due to 1% change in price and it has been estimated to be between –1.6 and –0.8 for air travel (*9*).
2. Percentage change in price.
3. Percentage of Cost Transferred to Passengers. It is the actual percentage of cost airlines pass onto the passengers since they might not be able to pass on all their additional cost.

Higher Congestion, Longer Travel Time This loop illustrates how an increase in congestion delays results in a decrease in airport demand because of deteriorating level of service (bigger dotted lines in Figure 1).

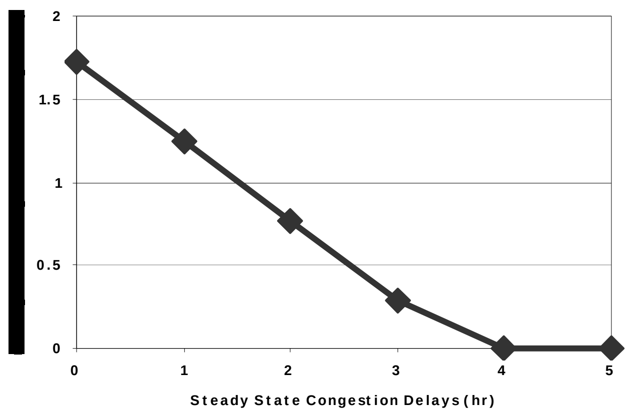
Level of Service is a measure that describes performance conditions in terms of operational characteristics of interest to users (*10*). In case of air transportation, Level of Service is directly related to the experience of the passengers, such as travel time, comfort and convenience. Congestion delays at the airport decrease the Level of Service by lengthening travel time, which in turn reduces the demand for the airport. Level of Service Impact shows how much the runway demand changes due to changes in average travel time to the airport, and it depends on the time elasticity of demand. Time elasticity of demand is the percentage change in passenger demand due to 1% change in average travel time and it is considered to be between –0.8 and –1.6 for air travel (*9*). Figure 3 shows that for a given increase in congestion delays, Level of Service Impact causes a larger change in airport demand than Airfare Impact does.

FIGURE 3 Individual Effects of Congestion Loops on Change in Runway Arrival Rate.



Change in Runway Arrival Rate is the total change in the number of aircraft that is scheduled for that year. It is a function of the congestion at the airport as well as exogenous demand for that year. Studies show that there is a strong demand for air transportation services (*11*). Given a latent demand of Annual Passenger Growth Rate (5000 passengers/year), only 3.8% of these passengers actually fly. Figure 4 shows how Runway Arrival Rate changes due to changes in Congestion Delays. As congestion increases, the additional demand for that year decreases.

FIGURE 4 Combined Effects of Congestion Loops on Change in Runway Arrival Rate.



Capacity Growth This loop illustrates the infrastructure improvement decisions as a function of three user inputs. Each combination of these three inputs determines a specific investment strategy that implements different choices on undertaking new projects to improve the airport capacity.

First user input is “When to Increase Capacity”. This is the target runway utilization ratio, which triggers the capacity enhancement projects to start. When this target runway utilization is reached, a new project is undertaken. No simultaneous projects are allowed.

“When to Increase Capacity” and current Runway Capacity determines Congestion Threshold, the maximum level of congestion delay allowed before more capacity is added to the airport. A low threshold reflects a proactive strategy by which the decision maker intends to have enough capacity to meet demand. On the other hand, a high threshold represents a reactive strategy by which the decision maker waits till it is obvious that the current levels of demand require more capacity. If the runway capacity is held constant, increasing the runway utilization increases congestion nonlinearly. Therefore, reactive strategies with higher runway utilizations allow higher congestion delays before expanding capacity of the airport.

Second user input is “How Much to Increase Capacity”. This is the amount of capacity the new project will add to the current capacity as a percent of the current capacity. In this analysis, three values are considered:

1. 10*%*. Examples include modifications to existing approach procedures and better sequencing of arrival aircraft by automation support tools.
2. 25*%*. Examples include the installation or upgrade of instrument landing systems, expansion of taxiways and holding areas.
3. 50%. Examples include completely new taxiway or runway.

Capacity Increase is the exact amount of capacity to be added to the runway for that particular project. It depends on the runway capacity when the project is initiated as well as the level of Congestion Threshold. As the Runway Capacity increases, the amount of capacity to be added with each project increases even though How Much to Increase Capacity is held constant.

Third input is "Years to Increase Capacity". This is the time frame for the new undertaken infrastructure project to be completed.

Rate of Capacity Delivery represents the amount of capacity that is delivered each year to the airport. It is assumed that the undertaken project will increase runway capacity incrementally proportional to the number of years it takes to complete it.

3.2. Additional Features of the Model

The air transportation infrastructure model developed in this paper is based on the model from Miller & Clarke (2003). However, there are differences between two models:

1. This model calculates the additional capacity to be added from the current level of Runway Capacity rather than adding a constant level of capacity every project. Thus, the amount of cost and capacity delivery changes depending on the start time of the project.
2. This model does not allow simultaneous project.
3. This model caps congestion delays at 18 hours and does not allow negative delays.
4. This model calculates Steady State Total Number of Peaks as another performance measure for the chosen investment strategy.
5. This model calculates NPV of investment for each possible decision alternative rather than as a difference from a baseline scenario.
6. This model calculates the mean and standard deviation of other important outputs, such as Runway Capacity, Runway Arrival Rate, and Average Steady State Congestion Delays, to see the trade-offs between investment opportunities.

The biggest difference between two models is the variable called "Steady State Total Number of Peaks". This variable is used to create the trade-space for available investment strategies.

3.3. Analysis Process

Analysis process starts with determining the investment strategy scenarios to be included in the portfolio. Each scenario is defined as a combination of three user inputs described in Section 3.1. In this paper, the explored choices for these inputs are:

1. When to Increase Capacity :60%, 75%, 90% (Runway Utilization)
2. How Much to Increase Capacity :10%, 25%, 50% (of Current Capacity)
3. Years to increase capacity :1,5,10,15 (Years)

Thus, there are 36 scenarios to be simulated. Then, these scenarios are simulated using the dynamic system model developed.

For the stochastic portfolio analysis, it is assumed that there are five sources of uncertainty in the model. These five variables are assigned random uniform distributions in the ranges given below:

1. Annual Passenger Growth Rate : [1, 10000] passengers
2. Average Travel Time : [2, 4] hrs
3. Percentage of Cost Transferred to Passengers: [0.6, 0.9]

4. Price Elasticity of Demand : [-0.8, -1.6]
5. Time Elasticity of Demand : [-0.8, -1.6]

For each scenario, Monte Carlo simulations are run using Vensim sensitivity function. Initial number of runs is selected as 200 simulations. The rest of the simulation budget is allocated amongst 36 scenarios using OCBA technique. OCBA determines how many more simulation runs are needed for each scenario by using the mean and standard deviation of NPV of Investment (*12*). When the simulation budget is spent (600 simulations), values from the last Monte Carlo run is selected as the outputs of that scenario. There are five outputs of the model:

1. NPV of Investment (at the end of 50 years)
2. Steady State Congestion Delays (average of 50 years)
3. Runway Capacity (at the end of 50 years)
4. Runway Arrival Rate (at the end of 50 years)
5. Steady State Total Number of Peaks (at the end of 50 years)

The mean and standard deviation of these five outputs over all the simulation runs are also calculated as part of the scenario results.

4. Results

4.1.Results of the Deterministic Dynamic Systems Model for Air Transportation Infrastructure

The deterministic run for the model is done by using mid-point for uniform distributions of all stochastic input parameters.

Steady State Total Number of Peaks indicates how many times current airport demand will exceed the airport capacity in the next 50 years. When this value is greater than zero, extra financial resources are needed to correct the capacity downfall than originally planned in the chosen strategy. The more total peaks a scenario has, the more times airport authorities will need to search for additional financial resources. Therefore, scenarios that have zero Steady State Total Number of Peaks are defined as the feasible solution set for the optimization. From these feasible solutions, the scenario with the maximum NPV of Investment at the end of 50 years is selected as the optimum solution.

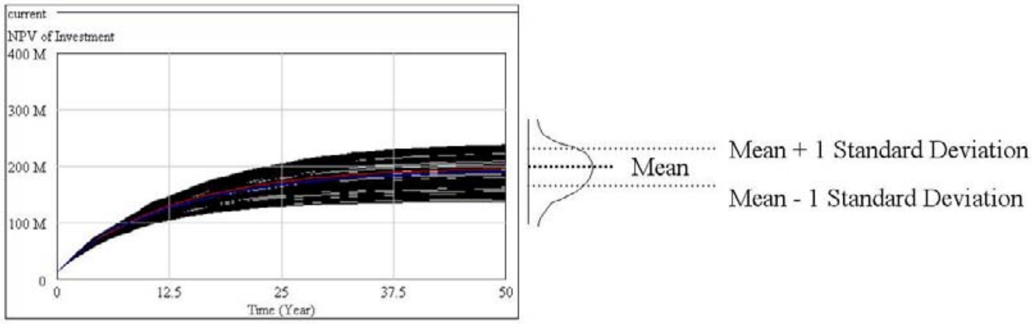
Results show that feasible solution set does not include scenarios with the highest NPV of Investment. On the other hand, scenarios with high values of Runway Capacity are included. This shows that there is a trade-off between how much congestion is allowed before extra capacity is added to the airport and how much that extra capacity costs. Even though higher runway capacity brings more passengers to the airport with lower congestion delays, it might also be costly if this extra capacity is left unutilized.

The results for the deterministic runs show that the best strategy is to increase capacity 25% with short lead times (5 years) reactively (when capacity is utilized 90%).

4.2. Results of Monte Carlo Simulations

When total number of simulation runs allocated to a scenario is completed, the output values at the end of 50 years from all simulations are taken to calculate the mean and standard deviation of that output. Since input distributions are allowed to vary in Monte Carlo runs, each of the 200 simulations calculates a different value for NPV of Investment, even though all input parameters are the same. Figure 5 shows how NPV of Investment changes among 200 runs associated with a particular scenario. For Steady State Congestion Delays, the average value over 50 years is taken instead to calculate its mean and standard deviation.

FIGURE 5 Values for NPV of Investment for A Scenario as A Sample of Stochastic Results.



Risk attitude of the decision maker can be represented in the model through Steady State Total Number of Peaks. For a particular investment scenario, if the mean of Steady State Total Number of Peaks is found to be zero with a standard deviation, then mean plus one standard deviation results in a positive value. This positive value means that there is a risk associated with that scenario that there could be capacity problems in the future. This risk is associated with facing an undesirable situation where additional funds are required to fix a problem (congestion at the airport) which the chosen investment strategy was supposed to solve. A risk-averse decision maker will stay away from such an outcome, whereas a risk-taking decision maker will prefer it to receive greater value. Thus, from the viewpoint of Steady State Total Number of Peaks, the value of mean Steady State Total Number of Peaks plus one standard deviation implies risk-averse decision maker, and mean minus one standard deviation implies risk-taking decision maker. Risk-neutral decision maker could also be represented by using only the mean value of Steady State Total Number of Peaks without considering the standard deviation.

The results of Monte Carlo runs show that the feasible solution set for risk-averse decision makers gets smaller as more congestion is allowed at the airport before increasing capacity. Risk-averse decision maker has 6 feasible scenarios in proactive scenarios (which increase capacity when capacity is utilized 60%) as opposed to 3 feasible scenarios in reactive scenarios (which increase capacity when capacity is utilized 90%).

As the decision maker becomes more risk-taking, the feasible solution set gets larger. For example, there are 10 feasible scenarios available to risk-taking decision makers as opposed to 3 scenarios for risk-averse decision makers under scenarios which increase capacity when capacity is utilized 90%.

As the uncertainty with the decision gets lower, the higher target runway utilization gives better results. The optimum solution has the highest NPV of Investment for risk-averse decision maker and the lowest NPV for the risk-taking decision maker.

Analysis results show that risk-averse decision makers should choose strategies that increase capacity moderately (10%-25%) with short lead times (1-5 years). Investments result in higher NPV as more reactive strategies are preferred. On the other hand, risk-taking decision makers should choose strategies that also increase capacity moderately (10%-25%) but with long lead times (15 years). Investments result in higher NPV as they prefer more reactive strategies, too. The optimum solution for risk neutral decision maker is the same as that of the deterministic run of the model.

(For further information, please see Mezhepoglu, Sherry 2006 (*13*))

5. Conclusion

The results of the air transportation infrastructure model show that there exists a tradeoff between the cost of any unutilized capacity that is added, and the cost of congestion not addressed by additional capacity.

Table 1 shows the trade-space for decision makers for choosing investment strategies. When capacity improvements are needed at the airport, often there are only couple options available for decision makers to choose from. These options have specific values of how much they could improve capacity and how long it would take to receive that intended improvement. What decision makers are left with is to decide which project to invest and when to start that project. The trade space for the outcomes of investment strategies analyzed in this paper are shown in Table 1 for given decision maker risk acceptance and a given start time for implementation. Each cell shows the optimum NPV of Investment achieved for associated target runway utilization rate and risk-acceptance of the decision maker. The scenario that gives this optimum value is also given in the same cell (When to Increase Capacity, How Much to Increase Capacity, and Years to Increase Capacity). It is found that the value of the investment is maximized for risk-averse decision makers when capacity is increased moderately (25%) with lead-times less than 5 years. Strategies result in more value as the decision maker gets more risk averse and strategies become more reactive.

TABLE 1 Trade Space for Decision Makers Showing Optimum NPV of Investment for Given Risk-Acceptance and Target Runway Utilization Rate.

		Monte Carlo Run (Risk-Acceptance)		
	When to Increase Capacity	**Risk-Averse** (spend more money now for one-time sustainable, long-term fix)	**Risk-Neutral**	**Risk-Taking** (spend less now but take the risk of fixing it again)
Proactive	at 60% Capacity utilization	$210.8 million Scenario: 60% utilization 25% capacity 5 years	$ 178.5 million Scenario: 60% utilization 25% capacity 5 years	$175.4 million Scenario: 60% utilization 10% capacity 15 years
	at 75% capacity utilization	$212 million Scenario: 75% utilization 10% capacity 1 year	$195.3 million Scenario: 75% utilization 25% capacity 5 years	$177.4 million Scenario: 75% utilization 10% capacity 15 years
Reactive	at 90% capacity utilization	$ 217.8 million Scenario: 90% utilization 25% capacity 1 year	$202.3 million Scenario: 90% utilization 25% capacity 5 years	$ 177.8 million Scenario: 90% utilization 10% capacity 15 years

This model illustrates the complexities faced by decision makers that must request large capital investments with long lead-times in the presence of large degrees of uncertainties. Unwarranted expansions at Kansas City and St. Louis are counter-balanced by timely development at Dulles, Denver, Atlanta and Chicago O'Hare (planned).

It should be noted that the underlying assumption of this capacity improvement mechanism is that the revenue for capacity improvement is generated through revenue-neutral fees imposed on the airlines. Future work is planned to investigate the dynamics of the system in the presence of fees based on demand for the scarce resources. Under this configuration, capacity improvement would be signaled by increases in fees that would stimulate innovation, productivity improvements, and capacity enhancements.

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