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 timely manner to ensure 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 unutilized capacity added and the cost of congestion allowed. Net Present Value is maximized for risk-averse decision makers and capacity is increased moderately (10%-25%) with lead-times less than 5 years.

1. Introduction

The air transportation system provides for the cost-effective transportation of goods and services. About 75% of long distance and 42% of medium distance travelers prefer air travel (*1*). Although this form of transportation is a significant driver of the economy, 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 enabling projections of the impacts by their policies especially in regards to transportation infrastructure because these projects can take up in some cases an entire decade (*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 unutilized capacity added and the cost of congestion allowed.
2. Net Present Value (NPV) is maximized for risk-averse decision makers and capacity is increased moderately (10%-25%) with lead-times less than 5 years.

This paper is organized as follows; Section 2 is background, Section 3 is methodology, Section 4 results, and Section 5 is conclusion.

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 (10%, 25%, 50%), the time to deliver capacity (1, 5, 10, 15 years), and the congestion threshold that triggers the need for capacity delivery (60%, 70%, 75%, 90%, 95%). 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 that 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 that congestion also leads to less demand by increasing travel time. The capacity loop models that 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 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. Congestion threshold of 75% should be the trigger for capacity enlargements if strategies based on small capacity increments and 1 or 5 years to increase capacity are considered. Furthermore, the choice of discount rate is critical importance for infrastructure decisions.

3. Method

The method used in this analysis is to develop a deterministic dynamic system model of the Air Transportation System performance including revenues, costs and NPV. The model was baselined on Miller & Clarke (2003) (Refer to Mezhepoglu, Sherry 2006 for more information on the differences between two models). This deterministic 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

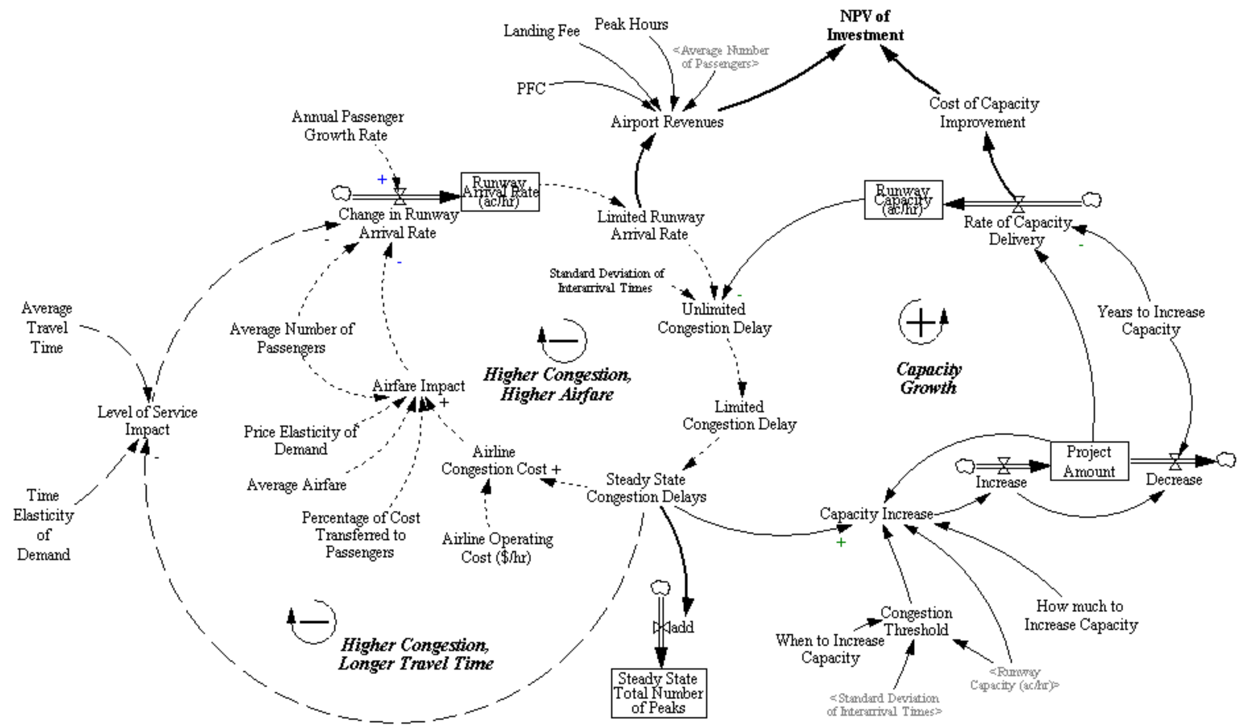
There are 36 scenarios investigated for the portfolio analysis. The amount of simulation runs for each scenario is determined using OCBA technique.

3.1 Deterministic Dynamic System Model for Air Transportation Infrastructure

The model is illustrated in Figure 1. The version of the model built in this paper is for one airport. The main output of the model is the NPV of the infrastructure investment called "NPV of Investment" (see upper right). The time step of the model is one year. The names of the variables used in the model are capitalized all throughout the paper.

NPV is a traditional valuation method for a project that expresses how much value an investment will result in. If NPV is positive, then the project should be undertaken. The NPV of Investment is calculated by discounting net cash flows per year. This is the difference between Airport Revenues (cash inflows) and Cost of Capacity Improvement (cash outflows) per iteration. The cost for the investment is assumed to be incurred at the end of each year proportional to the amount of capacity improvement received that year. A discount rate of 10% is used to adjust for time and risk taken.

FIGURE 1 The 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. Therefore, 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. In this paper, landing fees are assumed to be $200 per aircraft. Airport Revenues are calculated based on how many aircraft land in that year and how many passengers each aircraft carried. It is assumed that only narrow-body aircraft is operated (average seating capacity of 110) and congestion delay occurs only at a given number of peak hours per year (1,000 hrs/year).

Cost of Capacity Improvement is the cost of infrastructure enhancement finished in that 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. Then, Cost of Capacity Improvement is merely the multiplication of these two variables.

There are 3 loops in the model representing 3 different behaviors.

1. Higher Congestion, Higher Airfare
2. Higher Congestion, Longer Travel Time

3. Capacity Growth

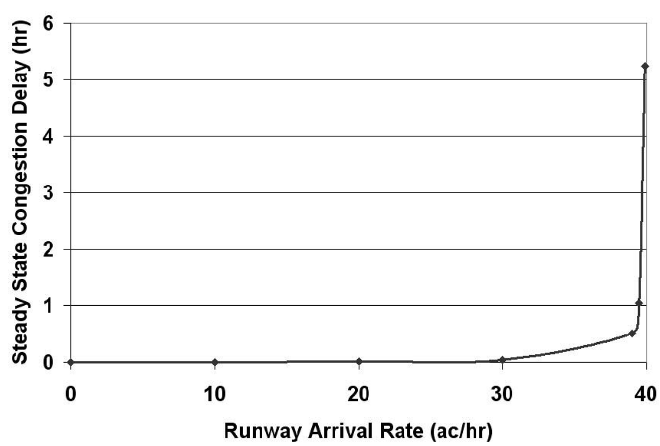
The right side of Figure 1 illustrates the supply side whereas the left side illustrates the demand side. Capacity Growth loop represents the supply side and shows how the capacity enhancement decisions are done. Both Higher Congestion, Higher Airfare and Higher Congestion, Longer Travel Time loops represent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

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

Unlimited Congestion Delay is defined as the waiting time for each aircraft that wants to land on the runway. The runway is modeled as an M/G/1 queuing system. In M/G/1 system, even if the mean service times stay unchanged, a decrease in the variability of service times can substantially reduce the queue size and customer waiting time. Standard Deviation of Interarrival Times captures this phenomenon and is assumed to be 20 seconds. Limited Runway Arrival Rate is the number of aircraft that wants to land on the runway in an hour and Runway Capacity is the number of aircraft that can land on that runway in an hour. Thus, Unlimited Congestion Delay is a function of these three parameters.

M/G/1 queuing formula assumes that the utilization rate should be less than 1 for the system to reach steady state. This means that the arrival rate for the runway is never greater than the runway capacity. Then, if the runway capacity is held constant, increasing the arrival rate increases congestion as shown in Figure 2. However, when this assumption is violated, the Unlimited Congestion Delay goes negative, representing the congested situations where there are more customers waiting in queue than the capacity could serve and the waiting time for customers goes to infinity. To avoid this, whenever Unlimited Congestion Delay goes negative, it is assumed that there is 18 hours (the number of hours in an operating day) of delay for the runway. This new delay variable is called Limited Congestion Delay. Furthermore, the Limited Congestion Delay goes infinity as the arrival rate gets closer and closer to the runway capacity as shown in Figure 2. Thus, Limited Congestion Delay is capped at 18 hours of waiting time and is called "Steady State Congestion Delays".

FIGURE 2 Relationship between Congestion Delay and Runway Arrival Rate.



When Steady State Congestion Delays reach 18 hours of delay, this is critical for the airport. It is a precursor that the selected strategy for capacity improvement is not working since the current capacity cannot satisfy the demand and additional financial resources than originally planned will be needed to solve this problem. Therefore, the number of times 18 hours of delay is reached throughout the simulation is captured by Steady State Total Number of Peaks.

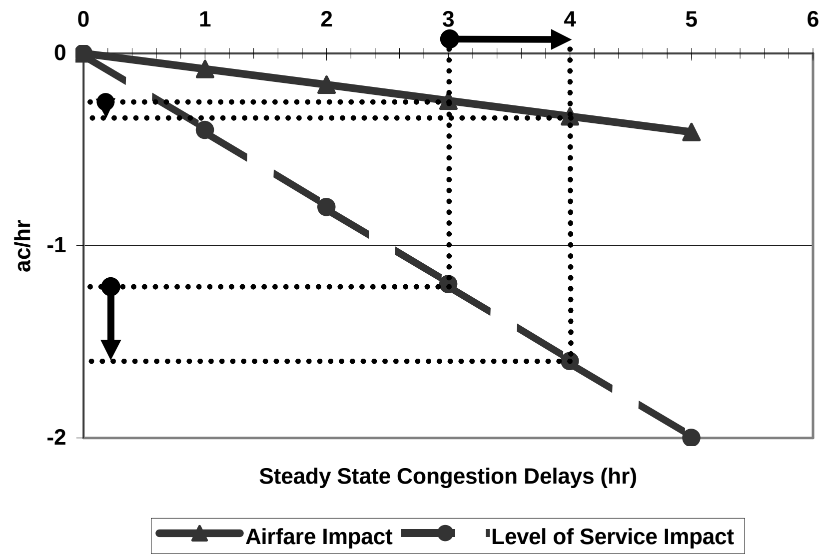
Airline Congestion Cost is the amount of additional direct operating costs airlines have to incur due to delays at the airport. It is calculated by multiplying the number of hours each aircraft get delayed with the Airline Operating Cost per hour ($2,000/hour).

The higher operating costs are passed on to the passengers in terms of higher airfares by airlines, which in turn lead to less demand for both airlines and the runway. Airfare Impact shows how much runway demand changes due to changes in average airfare. It is the multiplication of three factors. 1. The price elasticity of demand is defined as the percentage change in passenger demand due to 1% change in price. Price elasticity of demand for air travel has been estimated to be between –1.6 and –0.8 (*9*). 2. Percentage change in price can be calculated by dividing Airline Congestion Cost per passenger by Average Airfare ($200/passenger). 3. Percentage of Cost Transferred to Passengers is the actual percentage of cost airlines pass onto the passengers since they might not be able to pass on all their extra cost.

Higher Congestion, Longer Travel Time This loop is shown in bigger dotted lines in Figure 1 and illustrates how an increase in congestion delays results in a decrease in demand for air services due to deteriorating level of service.

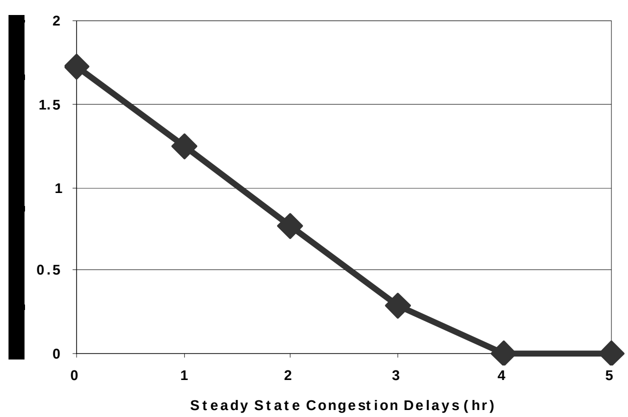
Level of Service is a measure that describes performance conditions in terms of operational characteristics of interest to users (*10*). In air transportation case, Level of Service is directly related to the experience of the passengers, such as travel time, comfort and convenience. Congestion delays decrease the Level of Service by lengthening travel time, which in turn reduces the demand for air services. Level of Service Impact shows how much the runway demand changes due to changes in average travel time. It is calculated by multiplying the time elasticity of demand with the percentage change in travel time. The time elasticity of demand is the percentage change in passenger demand due to1% change in average travel time and it is considered to be between –0.8 and –1.6 for air travel (*9*). To calculate the percent change in travel time, Steady State Congestion Delays is divided by Average Travel Time. Figure 3 shows that for a given increase in congestion delays, Level of Service Impact causes a larger change in demand than Airfare Impact.

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



There is also 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. Then, Change in Runway Arrival Rate is the total change in the number of aircraft that is scheduled for that year. It is where both demand loops join together. It is the sum of Airfare Impact, Level of Service Impact and exogenous demand for that year. 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 The Combined Effect of Congestion Loops on Change in Runway Arrival Rate.



Runway Arrival Rate is the total demand for the runway in number of aircraft per hour. It is the integral of Change in Runway Arrival Rate. However, this value can theoretically reach negative if both demand loops have more impact than the yearly growth rate or if the yearly growth rate is zero. Since negative runway demand has no meaning, this value is limited to only positive values and is called Limited Runway Arrival Rate.

Capacity Growth This loop illustrates the infrastructure improvement decisions as a function of three user inputs.

When to Increase Capacity is the target runway utilization ratio, which triggers the capacity enhancement projects to start. When this target runway utilization is reached, a new capacity enhancement project is undertaken. However, no simultaneous projects are allowed.

Congestion Threshold is the maximum level of congestion delay allowed before more capacity is added. 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 higher threshold represents a reactive strategy by which the decision maker waits till it is obvious that the current levels of demand require more capacity. It is a function of the current runway capacity and the target runway utilization ratio. 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.

How Much to Increase Capacity is the total additional amount of capacity to be added at the end of the capacity enhancement project as a percentage 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 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.

Years to Increase Capacity is the time frame for the infrastructure projects to be completed. Planned capacity is delivered incrementally to the airport in the time frame chosen. Rate of Capacity Delivery represents the amount of capacity that is delivered each year proportional to the project length. It is calculated by dividing Project Amount by Years to Increase Capacity, where Project Amount is equal to Capacity Increase.

Runway Capacity at any given year is the integral of the Rate of Capacity Delivery.

3.2. Analysis Process

First step for the analysis is to determine the scenarios for the portfolio analysis. The choices for 3 user inputs explored in this paper 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. Initial number of runs for each scenario is 200 simulations.

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]

Second step is to simulate these scenarios using the dynamic system model developed. To automate the simulation procedure, command scripts are written for each scenario inputs and outputs used. Monte Carlo simulation is run using Vensim sensitivity function. The simulation period is set to 50 years. 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 outputs over 200 simulation runs are calculated as the results for the Monte Carlo simulation. This process is repeated for all scenarios.

Third step is the allocation of the rest of the simulation budget amongst 36 scenarios using OCBA technique. OCBA uses the mean and standard deviation of NPV of Investment and determines how many more simulation runs are needed for each scenario (*12*). When the simulation budget is spent (600 simulations), the last Monte Carlo run is selected as the output for that scenario.

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.

The Steady State Total Number of Peaks is the indication of how many times the current demand for the airport will exceed the airport capacity in the following 50 years. When this value is greater than zero, the airport authorities will have to find extra financial resources than originally planned to correct the capacity downfall. Therefore, the more the total peaks a scenario has, the more times airport authorities will need to find additional financial resources to cope with the problem. 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 optimum solution is selected as the scenario that gives the maximum NPV of Investment.

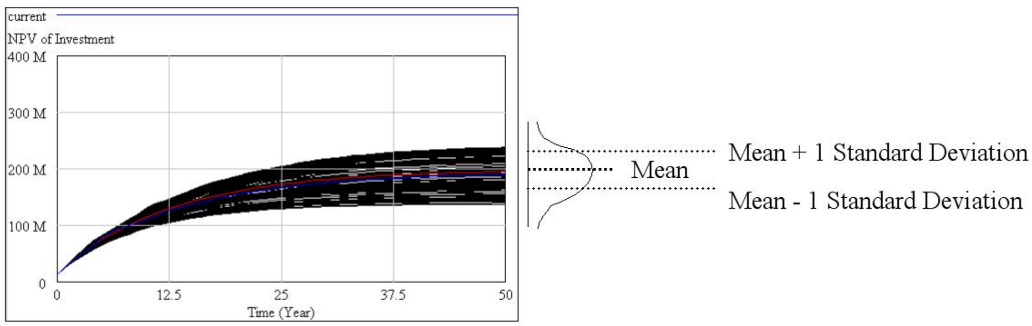
When the results for NPV of Investment are investigated, the scenarios with the highest NPV of Investment are not a part of the feasible solution set. On the other hand, the feasible scenarios have higher values for Runway Capacity. Even though higher Runway Capacity brings more passengers to the airport (Runway Arrival Rate) with lower Congestion Delays, it might also be costly if this extra capacity is left unutilized. Therefore, there is a trade-off between how much congestion is allowed and how much cost is incurred for additional capacity.

The results for the deterministic runs show when target runway utilization is set to 60% or 75% (i.e. proactive), the best investment strategy is to increase capacity 50% in 15 years. However, if target runway utilization is set to 90% (i.e. reactive), the best investment strategy becomes to increase capacity 25% in 5 years.

4.2. Results of Monte Carlo Simulations

Figure 5 shows the values of NPV of Investment for 200 initial runs associated with one of the scenarios. 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. When total number of simulations allocated to a scenario is completed, the end values of the output at year 50 from all simulations are taken to calculate the mean and standard deviation of this output. 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.



Taken from the point of view of Steady State Total Number of Peaks, mean plus one standard deviation implies risk-averse decision maker, where as mean minus one standard deviation implies risk-taking decision maker. In other words, if the mean for Steady State Total Number of Peaks is found to be zero with a standard deviation in a particular scenario, then mean plus one standard deviation will results in a positive value for Total Number of Peaks. This positive value means that there is a risk associated with that scenario that there could be capacity problems in the future. A risk-averse decision maker will stay away from such a scenario.

The results of Monte Carlo runs show that the feasible solution set gets smaller as target runway utilization gets larger for risk-averse decision makers. For the target runway utilization rate of 60%, there are 6 feasible scenarios that have zero Steady State Total Number of Peaks for risk-averse decision maker. However, there are only 4 feasible scenarios when the target runway utilization is at 75% and 3 feasible scenarios when the target runway utilization is at 90% for risk-averse decision makers.

As the decision maker becomes more risk-taking, the feasible solution set gets larger. For example, at 90% target runway utilization, there are only 3 feasible scenarios for risk-averse decision makers where as there are 10 scenarios available to risk-taking decision makers.

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.

For risk-taking decision makers, the optimum solution lies when capacity is increased 10% in 15 years with higher target utilization rates. For risk-neutral decision makers, the optimum solution is achieved when capacity is increased 25% in 5 years with higher target runway utilization. On the other hand, risk-averse decision makers reach optimum solution with strategies that increase capacity moderately (10%-25%) in short lead-times (1-5 years) with higher target runway utilization.

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

5. Conclusion

The results of the air transportation infrastructure model show that there is a tradeoff between the costs of unutilized capacity added and the costs of congestion allowed. This tradeoff exists for both deterministic and stochastic runs of the model.

The results of the model also show that the optimum strategy is different for deterministic and stochastic runs. The outcome of the investment is maximized for risk-averse decision makers and capacity is increased moderately (10%-25%) with lead-times less than 5 years. Table 1 summarizes the results. 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).

TABLE 1 Optimum NPV of Investment for Given Risk-Acceptance and Target Runway Utilization Rate.

	Deterministic Run	**Monte Carlo Run (Risk-Acceptance)**		
Target Runway Utilization Rate		**Risk-Averse**	**Risk-Neutral**	**Risk-Taking**
60%	$195 million Scenario: 60% utilization 50% capacity 15 years	$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
75%	$207 million Scenario: 75% utilization 50% capacity 15 years	$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
90%	$210 million Scenario: 90% utilization 25% capacity 5 years	$ 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

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