Evaluating the Economic Impact of ATM Innovations on Commercial Air Carrier Operations

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Abstract

The large investments required to develop and implement the next generation of air traffic management (ATM) innovations highlight the need for credible estimates regarding the financial impact to various stakeholders in the global air transportation community. A principal stakeholder in this community is the commercial aviation industry. Because of the highly competitive nature of the air travel industry, air carrier investments must be justified on the basis of a positive business case that addresses costs and benefits from the user's perspective and takes into account the full operational complexity of the air traffic system.

To support the NASA aeronautics research program, Logistics Management Institute is developing an integrated suite of models and databases called the Aviation System Analysis Capability (ASAC). The ASAC Air Carrier Cost-Benefit Model (CBM) was developed to analyse the financial impact to airline operators of investing in innovative technologies. Populated with data from several large air carriers, the CBM fills the gap between the highly aggregated methodologies used by government decision makers and the highly detailed proprietary models used by individual airlines.

The CBM interacts with a host of ASAC operations models such as the Airport Capacity and Airport Delay Models. Hence the analysis chain embodied by the CBM explicitly addresses the complexity of the integrated ATM system. The Model addresses a wide variety of costs and benefits by integrating an activity-based cost model of air carrier operating costs with a standard life-cycle cost model for new equipment acquisition.

This paper describes the CBM and presents the results of an analysis of a specific capacity enhancement program called low visibility landing and surface operations (LVLASO). LVLASO, part of the NASA Terminal Area Productivity (TAP) Program, seeks to augment existing airport capacity by reducing aircraft runway occupancy time, separation requirements, and taxi times in low visibility conditions. The operational impact of LVLASO is modelled using the Airport Capacity and Delay Models. Our analysis indicates that LVLASO

will provide modest benefits to air carriers, but contains substantial risk.

Introduction

To meet its objective of assisting the aviation industry with the technological challenges of the future, NASA must identify research areas that have the greatest potential for improving the operation of the air transportation system. Therefore, NASA seeks to develop the ability to evaluate the potential impact of various advanced technologies. By thoroughly understanding the economic impact of advanced aviation technologies and by evaluating how these new technologies would be used within the integrated aviation system, NASA aims to balance its aeronautical research program and help speed the introduction of high-leverage technologies. To meet these objectives, NASA is building an Aviation System Analysis Capability (ASAC).

NASA envisions the ASAC primarily as a process for understanding and evaluating the impact of advanced aviation technologies on the world economy. ASAC consists of a diverse collection of models, data bases, analysts, and other individuals from the public and private sectors brought together to work on issues of common interest to organizations within the aviation community. ASAC also will be a resource available to the aviation community to perform analyses; provide information; and assist scientists, engineers, analysts, and program managers in their daily work.

The ASAC differs from previous NASA modeling efforts in that the economic behavior of buyers and sellers in the air transportation and aviation industries is central to its conception. Commercial air carriers, in particular, represent an important stakeholder in this community. Therefore, to fully evaluate the implications of advanced aviation technologies, ASAC requires a flexible financial analysis tool that credibly links the technology of flight with the financial performance of commercial air carriers. In this way, NASA ensures that its technology programs will continue to demonstrate net benefits to the user community. Additionally, the model must be capable of being incorporated into the wide-ranging suite of economic and technical models that comprise ASAC.

This paper describes an Air Carrier Cost-Benefit Model (CBM) that meets these requirements. The ASAC CBM is distinguished from many of the existing aviation cost-benefit models by its focus exclusively on commercial air carriers. The model consider such benefit categories as time and fuel savings, utilization opportunities, reliability enhancements, safety and security improvements, and capacity enhancements. A distinction is made between benefits that are predictable and those which occur randomly. Such a distinction captures that ability of air carriers to re-optimize scheduling and crew assignment decisions in the face of predictable benefits. With regard to the costs of new technologies, the model incorporates a life-cycle cost module that applies non-recurring acquisition, recurring maintenance and operation, and training costs to each aircraft equipment type independently.

The core operating cost calculations of the CBM follow an activity based cost approach first developed for the Functional Cost Module of the Air Carrier Investment Model (ACIM). This approach estimates operating costs in six cost categories as a function of output, input prices, and input productivities. The default price and productivity parameters of the model are populated with publicly available data from the largest three U.S. carriers. Thus, the default model is developed for a representative airline which facilitates its use to build consensus regarding aviation investments. In addition, the model incorporates a database of alternate parameters which allows the user to customize analysis for specific air carriers or groups of air carriers.

The basic outputs of the model include net present value (NPV) and duration calculations. In addition, we have supplemented these basic outputs with a sensitivity analysis and simulation module that allows the user to select variables for sensitivity analysis and input data ranges. The sensitivity analysis algorithm produces a tornado diagram that summarizes the sensitivity of the results to independent variations in selected variables. The simulation algorithm uses Monte Carlo simulation to produce a distribution for the basic outputs as a function of the simultaneous variation in the selected variables.

Finally, this paper illustrates the use of the model in conjunction with other ASAC Models to evaluate the projected costs and benefits of a NASA research program called Low Visibility Landing and Surface

Operations (LVLASO). This program seeks to develop a set of innovations that reduce runway occupancy time and approach separation standards in poor weather and low visibility conditions. We find that the technologies of the LVLASO program will demonstrate net benefits to the representative air carrier, but contain substantial risk. The model identifies the variables that contribute to the range of uncertainty.

Overview of the Air Carrier Cost-Benefit Model

In creating the Air Carrier Cost-Benefit Model (CBM), we had some specific goals in mind. A primary objective was to create a flexible financial analysis tool to support credible estimates of benefits to airline operators from proposed technical and procedural innovations. Underlying this objective was a realization on the part of NASA that future technologies must demonstrate net benefits to the user community. In addition, we recognized the notion that existing aggregate level cost-benefit methodologies, which consider a much broader scope of benefits than those affecting only commercial air carriers, often lack sufficient operational complexity to establish credibility with airline operators. Therefore, with the realization that existing ASAC models are designed to address the broader scope of the integrated aviation community, we chose to focus exclusively on commercial air carriers for this model.

We envisioned the capability to evaluate the financial impact to airlines under a variety of user-defined technology scenarios. Since investments in new technology are subject to a great deal of uncertainty, we determined early on that a sensitivity analysis capability was essential. In addition, we envisioned the capability to input costs, benefits, and penetration assumptions differentially by aircraft equipment type. Finally, we envisioned the capability to customize analysis to represent specific air carriers or groups of air carriers.

Background

To satisfy these objectives, we undertook several activities prior to model development. First, we conducted an extensive review of related literature that included: a set of existing aviation cost-benefit methodologies and models, approaches and methods for modeling air carrier operating costs, and material related to forthcoming innovations in aircraft and air traffic management technologies. Second, we met with representatives from several major air carriers, a major airframe equipment manufacturer, an industry focus group, and key NASA personnel to discuss the requirements for the model and obtain input into our development process. Third, we undertook an analysis of the suitability of publicly available data sources to populate the parameters of the model. Finally, we specified a preliminary design for the model and obtained feedback from the industry and NASA representatives. The most significant findings from this background research are discussed in the following paragraphs.

Review of Related Literature

We reviewed a total of nine aviation cost-benefit models and methodologies.[1] To assist in organizing the materials, we developed a two dimensional classification system. The first dimension was the scope of the costs and benefits considered by the model. The scope of the models ranged from extremely narrow, in which the costs and benefits were limited to a single equipment type, to extremely broad in which the benefits to the aviation community, flying public, and general society were considered. The second criterion was the level of detail of the modeling approach. Methods ranged from highly detailed bottom-up approaches, in which the operating costs were calculated differentially by phase of flight and equipment type, to aggregate level top-down approaches in which industry averages were applied uniformly to all equipment types and carriers. As expected there was a high degree of correlation between these dimensions. Figure 1 summarizes our findings.

[1] Documentation on the models reviewed is available separately from the authors.

Figure 1. Existing Aviation Cost-Benefit Methodologies

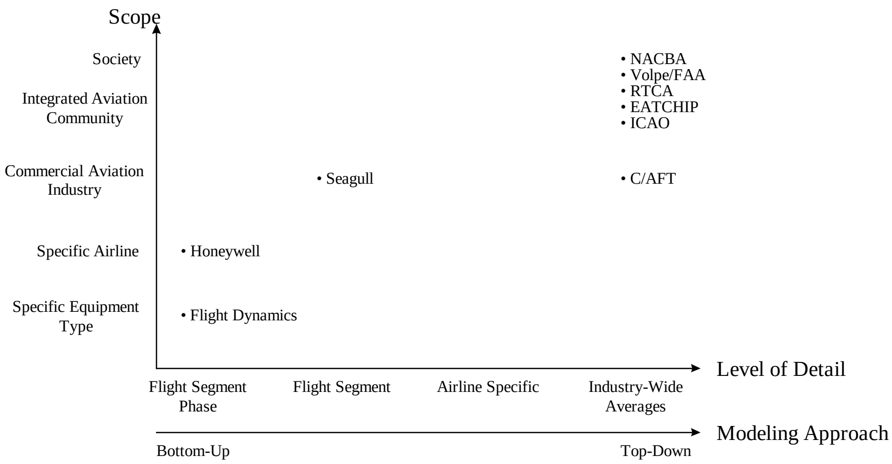


Figure 1 also illustrates the most important finding from our review. Other than airline proprietary analysis, no general cost-benefit models exist that focus exclusively on the air carriers and model operating costs at an appropriate level of detail. This finding echoes concerns we heard during our visits with industry representatives. Therefore, we concluded that many of the existing models either did not provide enough modeling detail, or attempted to provide more detail than could credibly be modeled in a financial analysis framework. An example of the former is that most models did not distinguish operating costs by aircraft type. An example of the latter is that several of the models differentiated fuel burn by phase of flight through the use of differential thrust settings. While important to consider, our contention is that an analysis of such topics is more appropriately conducted with an operational model, such as the ASAC Flight Segment Cost Model, than with a financial analysis model. Therefore, we envisioned a cost-benefit model that recognized the important distinction between operational issues and financial analysis issues. Fortunately, the broad scope of ASAC Models allows for such a distinction.

Another issue that emerged from our review of cost-benefit models was the need to establish a baseline scenario from which financial impacts could be assessed. That is, in many of the models reviewed, it was not clear what baseline the benefits of new technology were being measured against. In the case of time savings, for example, it was not clear whether time savings were measured against the current operating environment or some predicted environment of the future. The ASAC CBM eliminates this confusion by measuring the impact of technology against a clearly defined baseline scenario. Furthermore, the baseline assumptions are fully editable allowing a user to define a customized baseline.

Modeling Approach

The ASAC approach, in general, is one in which analysis is conducted by linking the inputs and outputs of distinct models to form an analysis chain. For example, a new air traffic management technology is first evaluated with an operational model such as the Airport Capacity Model to determine the impact on capacity. Output from the Capacity Model is subsequently passed to the Airport Delay Model to evaluate the impact on delay. Finally, delay figures are passed to an economic model of air carrier costs, such as the Functional Cost Module to evaluate the potential savings. In this way, the ASAC approach ensures that operational issues are addressed with operational models and economic issues are addressed with economic models. Thus, we envisioned a cost-benefit model that focused primarily on financial analysis issues and relied on other ASAC models for operational inputs.

The CBM takes a bottom-up approach in which operating costs are estimated at the aircraft equipment level and aggregated to obtain airline costs. Thus, the parameters that determine aircraft direct operating costs, such as crew labor rates, are different for each type of equipment. However, some parameters, such as those that determine revenue and indirect operating costs, are only available at the airline level of aggregation. The default parameters of the model are derived from the most recent DOT Form 41 Reports for the largest three U.S. carriers—American, Delta, and United. Thus, the parameters of the model represent a hypothetical airline composed of a weighted average of these carriers. Therefore, financial analysis using the default parameters of the model is representative of a large major carrier.

In addition to the default parameters of the model, we have also developed a database of alternate parameters for each carrier or carrier group—such as small majors, or nationals. This database allows analysis to be tailored to a particular set of carriers. Like the default parameters, the alternate parameters are drawn from publicly available Form 41 Reports. This database has been seamlessly integrated with the graphical user interface so that the default parameters may be easily overwritten. There are a total of 16 airlines that can be considered as well as 4 airline groups.

From the beginning, we envisioned a sensitivity analysis and simulation capability that would assess the sensitivity of the results to variations in key assumptions. We made a distinction between sensitivity analysis, in which the impact of deviations in one assumption are evaluated holding all other assumptions constant, and simulation analysis, in which Monte Carlo simulation is used to assess the impact of varying all assumptions simultaneously.

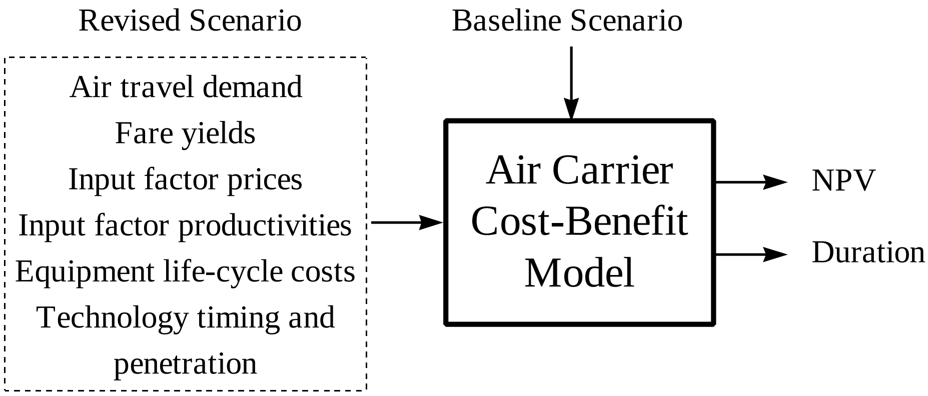
Derivation of the Air Carrier Cost-Benefit Model

This section describes the derivation of the CBM. We begin with a high level discussion of the model's structure. We then discuss the types of benefits that can be addressed by the model. This discussion is followed with a description of the life-cycle cost module that is used to estimate costs streams associated with new technology. We then discuss the model's core operating cost calculations that employ a variant of the activity based cost approach developed for the Air Carrier Investment Model. Finally, we discuss the output of the model.

Structure of the Model

Like other ASAC models, the CBM measures the impact of technological change against a clearly defined baseline. Analysis, therefore, requires the specification of two distinct scenarios—a baseline scenario and a revised scenario. The baseline scenario is intended to capture the most likely future set of outcomes in the absence of new technology (other than innovations explicitly treated in the forecast). We have provided a set of default assumptions which we believe accurately reflect the future expectations. However, we have also provided the capability to modify all of the baseline assumptions so that a user may specify a customized baseline. Conversely, the revised scenario is intended to capture the most likely set of outcomes in the presence of additional new technology. Thus, any differences between the revised scenario and the baseline scenario, with regard to the financial status of the carrier, are attributed to the incremental new technology. Figure 2 illustrates this concept.

Figure 2. Air Carrier Cost-Benefit Model Schematic



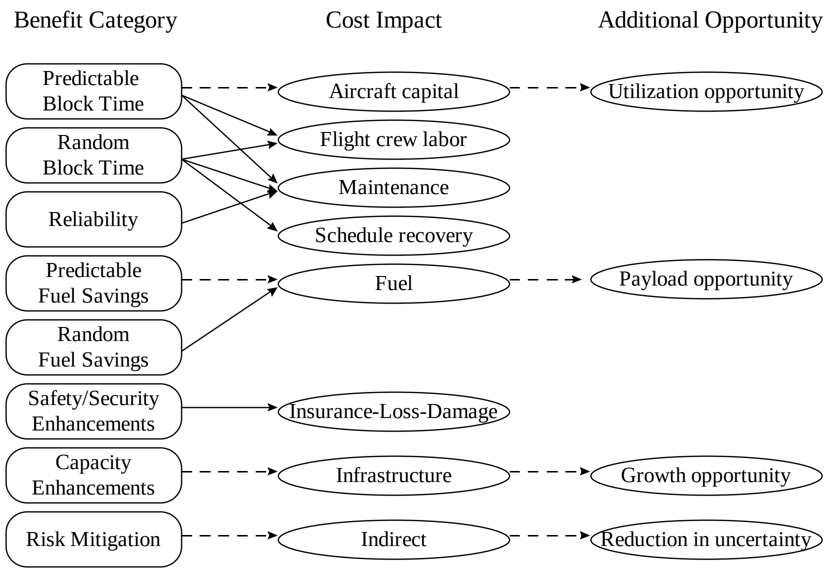
As shown in Figure 2, the primary inputs to the model consist of a baseline scenario and a set of revised assumptions that capture the impact of technology. This set includes parameters related to air travel demand, airline cost and productivity, life-cycle costs for new equipment and training, and the timing and penetration of the technological impact. The main outputs of the model are NPV and duration calculations. In addition the user may access a set of additional outputs such as annual cash flows, operating costs, and operating revenue by equipment type or aggregated at the airline level. Not shown in Figure 2 is the sensitivity analysis and simulation capabilities.

Benefits Assessed by the Model

From our review of existing cost-benefit models we identified a set of standard benefit categories for inclusion in the model. While any variable in the model may be modified to assess the benefits of technology, these categories represent the most likely drivers of future benefits. In several cases these categories represent predefined links between the primary impact of an innovation on cost, and subsequent secondary impacts such as revenue enhancement. The main types of benefits that are addressed by the model are shown in the first column of Figure 3. Each benefit category has a primary impact on costs as shown in the second column. Some categories lead to further impacts by enabling additional benefit opportunities. For example, in the case of predictable fuel savings, additional payload opportunities arise for flights that are currently payload or range constrained. Benefit categories that enable additional opportunities are denoted in Figure 3 with dashed lines.

We make a distinction between predictable and random time and fuel savings. Generally, predictable savings are more valuable than random savings because predictable savings allow the airline to re-optimize the scheduling and fuel load calculations. This is reflected in Figure 3 with predictable time and fuel savings leading to additional opportunities while random savings do not. In actuality, the value of predictable savings also depends upon the time horizon as described in Reference [4].

Figure 3. Benefit Categories



Utilization Opportunity

When predictable time savings are realized, it may be possible for an aircraft to obtain an additional flight segment at the end of a schedule day. To determine whether predictable time savings are sufficiently large, we compare the predicted time savings with a critical value that depends upon the flexibility of the airline's aircraft and crew scheduling decisions. The basic question we are addressing is what magnitude of savings are required to generate additional flight segments at the end of a schedule day. On one extreme we assume that there is no flexibility in the scheduling decision. In that case, each aircraft in the fleet must generate enough time savings itself to allow an additional flight. So, for example, if a particular aircraft flies 5 flight segments per day at an average block time of 2 hours per flight, then—abstracting from the possibility of increasing the number of daily block hours—a total savings of 20 minutes per flight is required to generate one additional flight. As shown in Equation 1—in which the subscript 0 denotes the period before the realization of time savings and 1 denotes the time period after—the algorithm used by the model also incorporate the possibility that the number of daily block hours may be increased.

$$\text{Critical Value}_{\text{Low}} = \text{Average Block Time}_0 - \frac{\text{Total Block Time}_1 (\text{per aircraft})}{(\text{Daily Flight Segments}_0 (\text{per aircraft}) + 1)}$$

Thus, this equation calculates the minimum amount of time savings required for each aircraft to generate one additional flight segment as a function of the average block time, the number of flight segments per day, and the total block time per day. Therefore, the number of additional flights is given by the following equation in which fleet denotes the number of aircraft of a particular type.

$$\text{Additional Flights}_{\text{Low}} = \text{Fleet} \times \text{Trunc}\left(\frac{\text{Time Savings}}{\text{Critical Value}_{\text{Low}}}\right)$$

At the other extreme we assume that there is unlimited flexibility in the scheduling decision. In this case, the time savings of each aircraft contribute to a general pool that determines the number of additional flight segments possible. The following equations represent the critical value and number additional flights under the assumption of unlimited flexibility.

$$\text{Critical Value}_{High} = \text{Average Block Time}_0 - \frac{\text{Total Block Time}_1(\text{all aircraft})}{(\text{Daily Flight Segments}_0(\text{all aircraft}) + 1)}$$

$$\text{Additional Flights}_{High} = \text{Trunc}\left(\frac{\text{Time Savings}}{\text{Critical Value}_{High}}\right)$$

The actual number of additional flights generated is then determined by a weighted average of the low and high estimates. The weights are adjusted by the schedule flexibility parameter that ranges between 0 and 1.

The analysis described above is carried out separately for each aircraft type. We assume that the length, duration, and load factor for additional flights are equal to the average value for the relevant equipment type. We apply the average passenger yield to the traffic generated by the additional flight segments. Also, since aircraft capital expenses are assessed per aircraft per day the additional flight segments do not incur additional capital expenses. Thus, the net benefit of an additional flight is the difference between the revenue obtained and the variable operating costs incurred.

Schedule Recovery

When flights are running behind schedule, unforeseen time savings allow the carrier to recoup a portion of the costs associated with the delay. These schedule recovery benefits are in addition to any variable operating cost savings and capture the value from reducing the occurrence of passenger and baggage misconnect, crew and aircraft reassignment, and loss of customer goodwill. Because schedule recovery opportunities exist only when a flight is behind schedule, the magnitude of the benefits depends upon the proportion of flights expected to be behind schedule. According to Reference [5], in 1996 the system-wide proportion of flights arriving at or before the scheduled arrival time was 46.5 percent for the largest ten U.S. airlines. However, a total of 78.1 percent arrived within fifteen minutes of the scheduled arrival time which constitutes an "on-time" arrival for purposes of the DOT's *Air Travel Consumer Report* [2]. Since the penalty for being less than 15 minutes late is likely to be small, we incorporate this on-time convention and use a value of 21.1 percent for the proportion of flights behind schedule. This value is consistent with the 20 to 40 percent range reported in Reference [11].

We found several sources of information regarding the value of schedule recovery benefits. According to Reference [11], the value ranges from $5.00 to $50.00 per minute per flight depending upon the number of passengers. According to Reference [6], the value is approximately $0.25 per minute per passenger for delays less than 60 minutes. This works out to $30.00 per minute for a typical flight of 120 passengers which is consistent with the previous source. Since we estimate costs and benefits at the equipment level of aggregation, we chose to employ the figure of $0.25 per minute per passenger for our schedule recovery value parameter.

Payload Opportunity

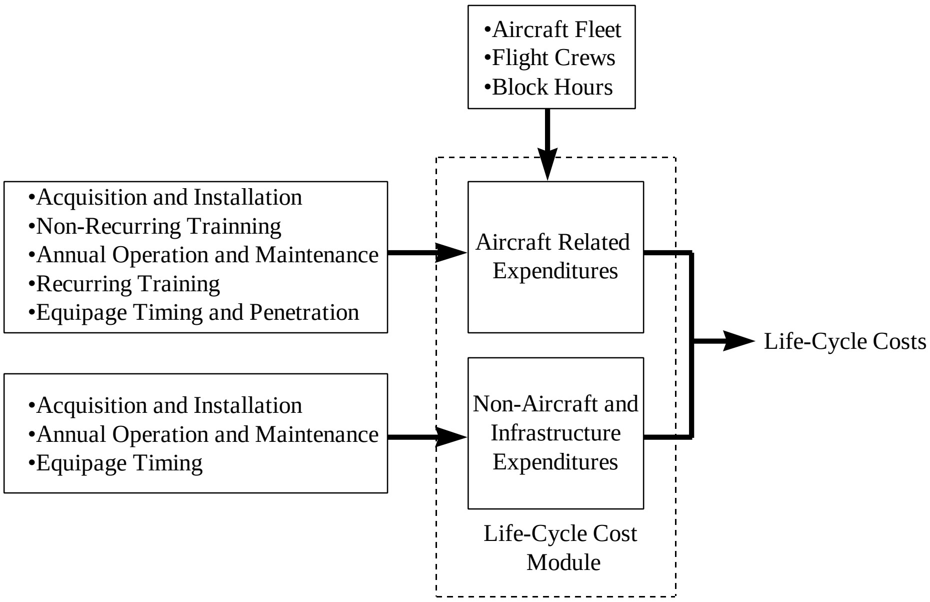
For flights that are payload constrained, predictable fuel savings also enable additional payload opportunities. The basic premise is that because the weight of the fuel load is reduced, the revenue payload can be increased. We assume that additional payload is exclusively in the form of cargo as opposed to passengers. To parameterize the benefits of payload opportunities it is necessary to determine the proportion of flights that are payload constrained. Reference [11] uses a value of 15 percent. Although this value may seem large, we were told by a major airline that the actual number of payload constrained flights was "surprisingly high." In light of these comments we chose a value of 15 percent for the proportion of flights payload constrained. Additional cargo is subsequently valued at the average cargo yield for the airline.

Life-Cycle Cost Module

To address the cost streams associated with innovation we developed a life-cycle cost module for the CBM. As shown in Figure 5, the life-cycle cost module consists of two primary components: aircraft related expenditures, and non-aircraft and infrastructure expenditures. While infrastructure expenditures operate at the airline level of aggregation only, aircraft expenditures can be input globally or differentially by equipment type. Aircraft related expenditures consist of: (1) acquisition and installation costs which are input on an aircraft basis, (2) non-recurring training costs which are input on a flight crew basis, (3) recurring operation and maintenance costs which are input on a block hour basis, and (4) recurring training costs which are input on a flight crew basis.

In addition to the cost items, the model requires certain equipage timing and penetration assumptions. These consist of: an initial equipage year, an initial proportion of the fleet, and a terminal proportion of the fleet. As shown in Figure 5, the life-cycle cost algorithm automatically draws input from the revised scenario to determine the number of aircraft, flight crews, and block hours impacted by aircraft related expenditures. The result is an estimate of the annual life-cycle cost stream for each equipment type affected. These are subsequently aggregated to determine the total impact to the airline.

Figure 4. Life-Cycle Cost Module Schematic



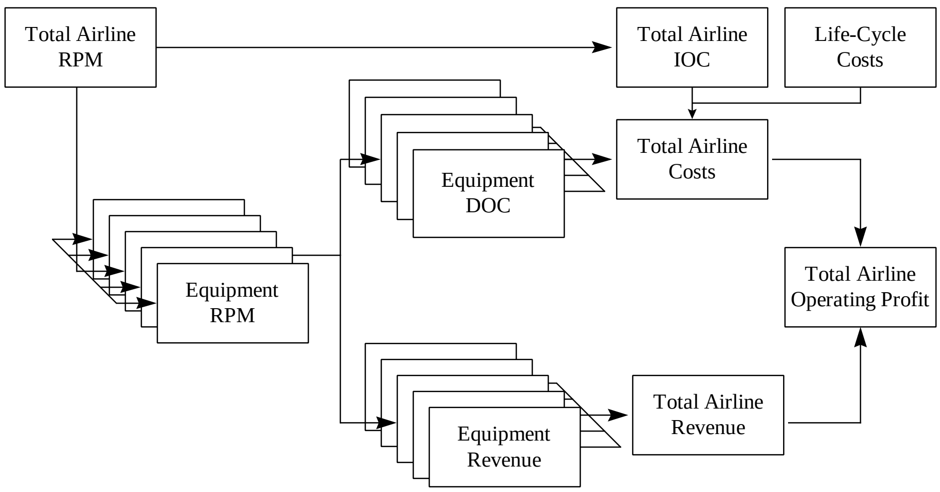
The infrastructure expenditures consist of non-recurring acquisition and installation costs, annual operation and maintenance costs, and an initial equipage year. The infrastructure costs are input as expenditures for the entire airline and are not dependent upon other inputs from the revised scenario. The infrastructure expenditures are subsequently combined with the aircraft related expenditures to produce an estimate of total annual life-cycle costs. Finally, the life-cycle expenditures are combined with operating cost and revenue projections to estimate airline profit. The following section discusses the calculation of direct operating costs.

Calculating Air Carrier Operating Costs

To estimate direct operating costs, the CBM follows an activity based cost approach originally developed for the Functional Cost Module of the ACIM [12]. The approach explicitly calculates operating costs in each of six categories as a function of total output, input factor productivities, and per-unit input prices. The cost analysis is based upon observations from DOT Form 41 data in conjunction with detailed aircraft fleet inventories from AvSoft’s ACAS Fleet Information System [1] and airline cost of capital information from Ibbotson Associates [8]. The cost data follow each air carrier with annual observations from 1985 through 1995.

Whereas the Functional Cost Module focuses on 26 air carriers and calculates operating costs at the airline level of aggregation, the CBM focuses on a single carrier and calculates operating costs at the aircraft equipment level. Figure 5 illustrates this concept. The more finely detailed approach of the CBM allows the user to evaluate the impact of technology differentially by equipment type. The model has the capability to consider up to 23 different equipment types. This set includes the 18 equipment types in use at year end 1996 by the largest three carriers, an additional 4 equipment types in use by the alternate carriers, and a vacant equipment type for use in evaluating future aircraft models. To facilitate various types of analysis, the model accepts input parameters at the equipment level of detail, by groupings of equipment types, or globally. The predefined groupings capture such characteristics as single-aisle aircraft, multi-aisle aircraft, Boeing aircraft, and Airbus aircraft.

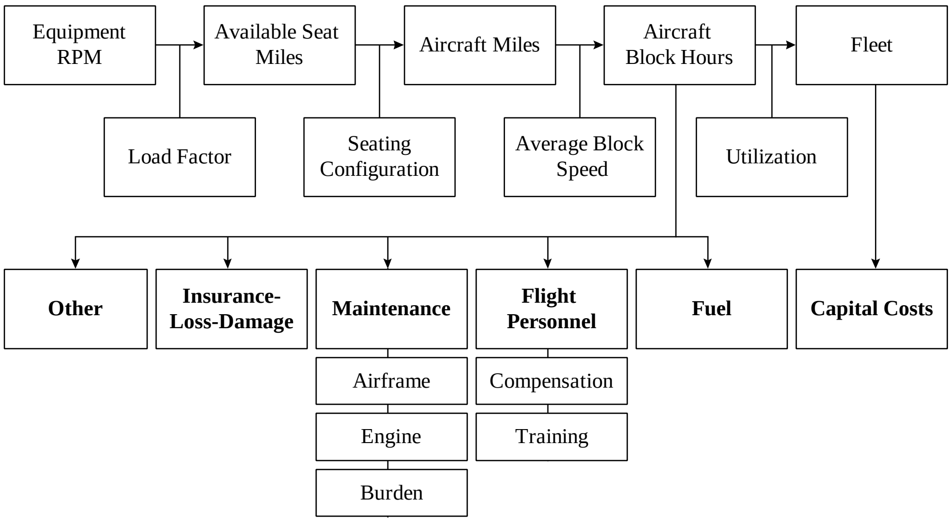
Figure 5. Calculating Airline Operating Costs.



As shown in Figure 5, the algorithm begins with the projected Revenue Passenger Miles (RPM) for the entire airline.[2] This aggregate traffic forecast is then allocated to each of the equipment types in accordance with certain RPM share assumptions specified by the user. These assumptions allow the user the flexibility to phase out older equipment types, grow existing equipment types, and add new equipment types. Passenger traffic at the equipment level, as measured by RPM, subsequently drives the calculation of direct operating costs and revenue. Further details regarding these equipment level calculations are provided below. Next, the equipment-level direct operating costs and revenue calculations are aggregated at the airline level. Estimates of indirect operating costs, derived from the airline-level traffic, are combined with cost estimates from the life-cycle cost module to obtain total airline costs. Finally, total operating expenses are compared with total operating revenues to determine operating profits.

[2] One revenue passenger (person receiving air transportation from the air carrier for which remuneration is received by the carrier) transported one statute mile.

Figure 6. Calculating Equipment-Level Direct Operating Costs.



To estimate equipment-level operating costs from equipment-level traffic projections requires several intermediate steps. As shown in Figure 6, the equipment level RPM forecast is first converted to available seat miles (ASM) using a set of equipment-specific load factor assumptions.[3] From ASM, we obtain the required aircraft miles using the seating configuration employed by the carrier. Using a set of equipment-specific assumptions regarding block speed, we obtain the number of block hours flown from the number of aircraft miles. Finally, we obtain the aircraft fleet requirements from the number of block hours using a set of equipment-specific utilization assumptions.

As shown in Figure 6, the majority of the operating costs are derived from the block hour projections. These consist of: fuel; flight personnel labor; maintenance; insurance, loss, and damage; and a residual category termed other direct expenses. Aircraft capital costs, however, are driven by the number of aircraft in the fleet as opposed to the number of block hours flown. This distinction allows the airline to take full advantage of any additional aircraft utilization benefits without incurring additional capital charges. Some cost categories contain more than one cost item. Maintenance costs, for example, are composed of aircraft and engine sub-categories in addition to overhead, or burden. Maintenance burden is driven by the sum of airframe and engine maintenance costs, as opposed to block hours.

Not shown in Figure 6, are the revenue calculations that apply the airline-level passenger yield assumptions to the equipment-level traffic projections. Such an approach abstracts from the reality that passenger yield varies significantly between equipment types mainly due to differences in average stage length. Unfortunately, DOT Form 41 revenue data are only available at the airline level of aggregation.

[3] One available seat of capacity transported on statute mile.

Figure 7. Operating Cost Calculations

$$\text{Fuel costs} = \text{block hours} \times \frac{\text{fuel price}}{\text{gallon}} \times \frac{\text{gallons}}{\text{block hour}}$$

$$\text{Flight personnel compensation} = \text{block hours} \times \text{labor rate (burdened)}$$

$$\text{Engine maintenance} = \text{block hours} \times \frac{(\text{maint. labor} + \text{maint. mat.})}{\text{block hour}}$$

$$\text{Airframe maintenance} = \text{block hours} \times \frac{(\text{maint. labor} + \text{maint. mat.})}{\text{block hour}}$$

$$\text{Maintenance burden} = \text{burden rate} \times (\text{airframe} + \text{engine maint.})$$

$$\text{Flight equipment capital costs} = \text{aircraft} \times \frac{\text{capital charges}}{\text{aircraft}}$$

$$\text{Insurance} \cdot \text{loss} \cdot \text{damage costs} = \text{block hours} \times \text{insurance} \cdot \text{loss} \cdot \text{damage rate}$$

$$\text{Other DOC} = \text{block hours} \times \text{other DOC rate}$$

Also not shown in Figure 6 are the calculations regarding air cargo. Air cargo traffic projections are obtained by applying equipment-specific cargo load assumptions to aircraft mile estimates. The result is a projection for the number of cargo revenue ton miles (RTM) flown by each equipment type.[4] Applying airline-level cargo yield assumptions to the equipment-level RTM projections produces an estimate of cargo revenue by equipment type. Finally, the revenue estimates are aggregated to obtain airline-level cargo revenues.

Within each cost category the operating expenses are determined by the interaction of one or more productivity parameters and a per-unit input cost parameter. For example in the case of fuel expenses, total costs are the product of total block hours flown (output), fuel consumption per block hour (productivity), and fuel price per gallon (input price). Figure 7 illustrates the calculations used by the model for each cost category.

With the exception of aircraft capital expenses, each parameter is derived from the equipment-specific base year DOT Form 41 observations. Thus, for each equipment type the base year cost estimates exactly match the carrier's Form 41 filing. To the extent that the parameters follow predictable trends, the cost estimates remain accurate over the forecast horizon.

Flight equipment capital costs were estimated in an especially detailed manner. We began with the 1996 inventory of aircraft from the AvSoft fleet database. This database provides detailed information on the age of each aircraft in a carrier's fleet. Using model-specific resale price information from Airclaims' International Aircraft Price Guide [9], we estimated the value of each aircraft as a function of its age. Summing over all of the aircraft in a carrier's fleet gives a measure of the total value of the flight equipment.

Next, we applied depreciation and cost of capital charges to the value of the flight equipment. The parameter for depreciation charges is 3.3 percent, which results form the standard straight-line approach with a useful life of 30 years and no residual value. The parameter for cost of capital charges is 9.8 percent which was derived by aggregating carrier-specific cost of capital charges published by Ibbotson Associates. Thus, the flight equipment capital costs were calculated as 13.1 percent of the carrier's aircraft inventory value. Like

[4] One ton (2,000 pounds) of revenue traffic transported one statute mile.

all parameters in the CBM, the cost of capital parameter represents a constant dollar value.

The advantage of this approach is that the resulting measure of capital cost includes the opportunity cost of the carrier's investment in equipment whereas depreciation charges taken directly from Form 41 reports do not. Thus we take an economic approach to determine the costs of capital as opposed to a less desirable accounting approach. Nevertheless, the impact of this economic approach must be considered when interpreting the operating profits output by the model. As in the Functional Cost Module, there is a discrepancy between the operating profits determined by the model and those reported in Form 41 caused by the opportunity cost of flight equipment capital. We call the profits measured by our approach *adjusted operating profit*.

With regard to indirect operating costs, we distinguish three cost categories. These consist of: landing fees, air traffic control charges, and a residual category termed other indirect charges. Although landing fees are incurred system wide, air traffic control charges are currently incurred only during international operations. An exception would be a flight between U.S. domestic locations that passes under the jurisdiction of a foreign air traffic control authority such as NAV Canada. Indirect charges are calculated using the same activity base cost approach as for direct charges. The cost driver for landing fees is the number of operations, while the driver for other indirect charges is ASM. Similarly, air traffic control charges are a function of the block hour rate and the percentage of block hours subject to charges. We approximate this percentage by the proportion of block hours incurred in international service.

Model Output

In addition to the sensitivity analysis capability, the model has several basic outputs. The first is a calculation of the net present value of the technology investment under consideration. The second is a calculation of duration which measures the time dimension of the cash flows.[5] In addition, the model provides access to many of the underlying calculations such as the discounted and non-discounted cash flows, total airline revenues and expenses under the baseline and revised scenarios, and equipment-specific cost calculations under the baseline and revised scenarios.

LVLASO Scenario

To illustrate the use of the CBM in the context of other ASAC models, this section implements an analysis chain that evaluates the benefits of a set of air traffic management technologies under the LVLASO program. LVLASO, part of the NASA Terminal Area Productivity (TAP) program, seeks to augment existing airport capacity by reducing aircraft runway occupancy time (ROT), separation requirements, and taxi times in low visibility conditions. LVLASO includes such technologies as the dynamic runway occupancy measurement (DROM) system, the aircraft roll-out and turnoff (ROTO) system, and the aircraft taxi-navigation and situation awareness (T-NASA) system. In addition, LVLASO requires the installation of several types of equipment both on the ground and in the cockpit. Figure 8 illustrates the analysis chain.

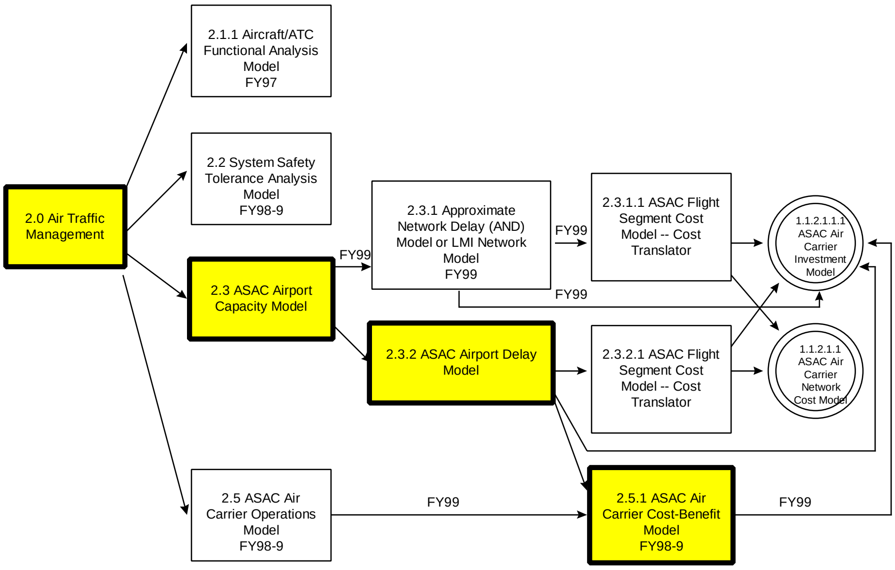
As shown in Figure 8, we begin our analysis with the ASAC Airport Capacity Model.[6] We model the impact of the new technologies on airport capacity independently for each of five major airports.[7] Airport capacity is a function of wind and weather conditions, airport configuration, and a set of technology related parameters such as ROT and arrival separation. Output from the Airport Capacity Model is subsequently passed to the ASAC Airport Delay Model which projects arrival and departure delay as a function of hourly demand and airport capacity. For each airport, we estimate delay with and without the capacity enhancing technologies. The projected difference between the two scenarios becomes input for the ASAC Cost-Benefit Model as described.

[5] For more information on the concept of duration see Reference [3].

[6] For more information on the ASAC Airport Capacity and Delay Models see Reference [10].

[7] The airports considered are ATL (Atlanta), DFW (Dallas-Ft.Worth), DTW (Detroit-Wayne County), LAX (Los Angeles), and LGA (New York LaGuardia).

Figure 8. LVLASO Analysis Chain



LVLASO Technologies

The National Aeronautics and Space Administration's Terminal Area Productivity program aims to safely achieve visible meteorological conditions airport operating capacity during instrument meteorological conditions.[8] The TAP program includes three technology elements: reduced spacing operations (RSO), low visibility landing and surface operations (LVLASO), and air traffic management (ATM). The LVLASO subelements are designed to cut delays on the runways and taxi ways during periods of poor visibility.

In addition to ground equipment requirements, the subelements of LVLASO require a set of upgrades to existing cockpit avionics capabilities. Table 1 lists the avionics requirements. The components included are based upon discussions with NASA personnel and on NASA briefings.

It is estimated that all of the LVLASO requirements can be satisfied with the acquisition of four equipment items. These consist of: (1) an additional VHF data radio, (2) HGS and software, (3) taxi map display and software, and (4) 3-D audio system (i.e., stereo headset, sound card, and software). In is important to recognize that these equipment items are also projected for use with other TAP technology elements. In addition, several of the equipment items, such as HGS, may be installed for other applications. Since our analysis fully applies the cost of the equipment against the LVLASO benefits, the results should be viewed as conservative benefit estimates. A complete evaluation of the TAP technology elements is beyond the scope of this paper.

[8] Information regarding TAP program elements is derived from Reference [7].

Table 1. LVLASO Avionics Requirements

Technology subelement	Requirement	
T-NASA	• Differential global positioning system (DGPS)	• Automatic dependent surveillance-broadcast (ADS-B)
	• Head-Up guidance system (HGS)	• Controller to pilot data link communications (CPDL)
	• Cockpit display of traffic information (CDTI)	• Taxi map display hardware/data
	• Audio card	• Stereo headsets
DROM	• DGPS	• ADS-B
ROTO	• DGPS	• HGS
	• Taxi map display hardware/data	

Deriving the Cost-Benefit Model Inputs

We model the impact of the LVLASO technologies on airport capacity by modifying the poor visibility—Instrument Meteorological Conditions (IMC2)—arrival ROT and separation standards to equal the good visibility—Visual Meteorological Conditions (VMC)—values for each aircraft class. The result is a revised capacity for poor weather conditions for each airport configuration that approximates good weather capacity.

Our technology scenario assumes that the benefits of the new technologies will be realized beginning in the year 2005. Accordingly, we specify projected traffic demand patterns for 2005 at each airport in the Airport Delay Model. The model uses a queuing engine to calculate the average arrival and departure delay on an hourly basis for each airport. For this analysis, we exercised the Airport Delay Model over an entire year of actual meteorological conditions for each airport. We then aggregated the hourly and daily results to obtain average delay statistics for arriving and departing flights on an annual basis. This analysis was performed for both a baseline and improved technology scenarios. The results from the Airport Capacity and Delay Models are summarized in Table 2.

Table 2. Projected 2005 Delay Statistics

Airport	Scenario	Average arrival delay (minutes)	Average departure delay (minutes)
ATL	Baseline	59.81	29.42
	LVLASO	55.52	25.92
DFW	Baseline	16.17	15.80
	LVLASO	15.85	16.02
DTW	Baseline	15.61	a
	LVLASO	12.72	a
LAX	Baseline	24.28	20.57
	LVLASO	23.90	20.36
LGA	Baseline	21.95	20.65
	LVLASO	19.71	18.60

a. The web version of the DTW Airport Delay Model does not calculate departure delay.

Since the CBM requires input in the form of changes in block time, the next step was to convert the figures from Table 2 to percent changes in block time. This requires an assumption regarding the average block time for departing and arriving flights at each airport. We used the 1995 DOT T-100 Reports to define the current average block time for each. These were subsequently adjusted by the projected increase in delay from 1995 to 2005 to determine the projected average block times for 2005. As described in an earlier section, the default parameters and assumptions of the CBM represent a large major carrier. Therefore, we used the T-100 Reports for the largest three carriers only to project average block time. The result was a projected change in arrival and departure average block times from the baseline scenario to the revised scenario for each airport.

To aggregate the impact of the technologies across all five airports we constructed weights according to the number of operations at each airport by the largest three carriers. The result is a weighted average change in block time that will be used to extrapolate to the system-wide impact. Table 3 illustrates this methodology.

Table 3. Deriving Cost-Benefit Model Input

Airport	Annual operations[a]	Change in arrival block time (percent)	Change in departure block time (percent)
ATL	199,073	-2.7118	-2.6593
DFW	246,276	-0.2014	0.1385
DTW	12,476	-2.3990	-2.3990[b]
LAX	98,331	-0.1863	-0.1110
LGA	52,147	-1.6803	-1.3773
Weighted		-1.1924	-0.9997

a. 1995 operations for American, Delta, and United.

b. In the absence of departure delay information for DTW we assume that departure delay equals arrival delay.

The final step in deriving the CBM inputs is to project the proportion of air traffic that will benefit from the new technology. Our LVLASO scenario assumes that these technologies will be in place at the 10 TAP airports by 2005.[9] In addition, we assume that the technologies will be installed incrementally at the next largest 10 airports over the remainder of the forecast horizon.[10] To determine a benefit penetration curve for our representative air carrier, we further examined 1995 T-100 Reports. For each flight segment in the T-100 Report, one of four possibilities must be realized. These possibilities are: (1) the flight segment both departs and arrives at airports with the new technologies; (2) the flight segment departs at an airport with the new technologies, but arrives at one without; (3) the flight segment departs at an airport without the new technologies, but arrives at one with; (4) the flight segment both departs and arrives at airports without the new technologies.

Categorizing each flight segment according to the criteria above yields estimates of the proportion of flights benefiting from the new technology. We exercised these criteria separately for 2005, with the 10 TAP airports, and 2016 for the top 20 airports. However, since the CBM can incorporate only a single parameter for change in block time, it was necessary to construct a weighted average across the these categories to represent the benefit penetration. This methodology is illustrated in Table 4.

[9] The ten TAP airports include: ATL, BOS (Boston), DFW, DTW, EWR (Newark), JFK (New York Kennedy), LAX, LGA, ORD (Chicago O'Hare), SFO (San Francisco).

[10] The next ten airports by operations are CLT (Charlotte), DEN (Denver), IAH (Houston), LAS (Las Vegas), MIA (Miami), MSP (Minneapolis-St. Paul), PIT (Pittsburgh), PHX (Phoenix), SEA (Seattle), STL (St. Louis).

Table 4. Penetration Assumptions

Departure airport	Arrival airport	Operations 2005 (percent)	Operations 2016 (percent)	Change in block time (percent)
LVLASO	LVLASO	14.9	31.3	-2.1921
LVLASO	Baseline	31.6	28.7	-0.9997
Baseline	LVLASO	31.6	28.7	-1.1924
Baseline	Baseline	21.9	11.3	0.0000
2005 Weighted average[a]				-1.3049

a. Conditional upon at least one airport having LVLASO.

Thus we adopt an initial benefit penetration of 78.1 percent with an initial reduction of 1.3049 percent in block time. Over the forecast period, the penetration grows to 88.7 percent although the impact remains constant. This assumption does not account for the fact that the block time impact itself is growing over time as more and more flights both depart from and arrive to airports with the new technology. For this reason, our estimates of the benefits of the LVLASO technologies should be viewed as conservative.

In order to evaluate the net benefits of the LVLASO scenario it is necessary to employ a set of life-cycle cost assumptions regarding the requirements for new avionics equipment. In a previously published report, we completed such a cost analysis for all of the TAP avionics requirements [7]. Table 5 summarizes the results of that study.

Table 5. Life-Cycle Cost Assumptions

Equipment item	Life-Cycle cost category	Expense
VHF digital radio	Acquisition	$30,000 per radio
	Installation	$1,000 + 4 hours out of service
	Recurring maintenance and operation	$0.10 per block hour
HGS	Acquisition	$219,000 per HGS
	Installation	$50,000 + 2 days out of service
	Initial training	$2500 per flight crew
	Recurring training	$500 per flight crew
	Recurring maintenance and operation	$1.00 per block hour
Taxi map display hardware/data	Hardware acquisition	$0.00 (currently in place)
	Data acquisition	$10,000 annually per fleet
3-D audio warning system	Headset and sound card acquisition	$2,000 per aircraft
	Installation	$200 + 2 hours out of service
	Recurring maintenance and operation	$0.05 per block hour
CDTI software	Acquisition	$1000.00 per aircraft

Aggregating the results from Table 5 we arrive at the following life-cycle cost assumptions:

- $355,200 per aircraft for acquisition and installation of new of cockpit avionics,
- $2,500 per flight crew as initial training expense,
- $1.15 per block hour as operation and maintenance expense,
- $500 per flight crew as recurring annual training expense.

Finally, our equipage penetration assumption is that all aircraft will be equipped during 2005 to take advantage of the block time benefits.

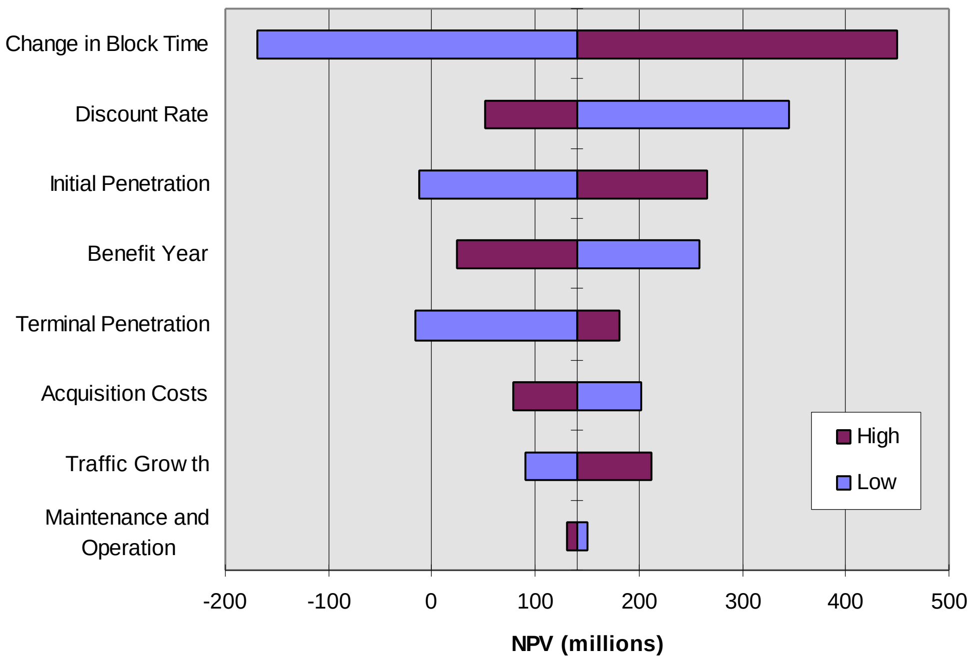
Scenario Results

We exercised the model under the assumptions discussed above. The main result shows that the LVLASO technologies do provide modest benefits to the representative carrier. We estimate the NPV of this investment to be $140.62 million at a discount rate of 8 percent. In addition, the investment has a large duration of 25.34 which correctly indicates that the stream of benefits is far into the future.

To analyze the sensitivity of the main results to variation in the input data, we exercised the sensitivity analysis module for several key variables. As shown in Figure 9, these include: change in block time, discount rate, penetration assumptions, life-cycle costs, and traffic demand growth. In exercising the sensitivity analysis module we made a simple assumption that the low and high values were 50 and 150 percent of the middle values respectively.

Under these assumptions, it is clear that the LVLASO technologies contain several risks that threaten the projected benefits. The most substantial risk is due to uncertainty in the magnitude of the block time savings. This issue might be particularly risky since the magnitude of the time savings depends upon the equipage of other carriers' aircraft. Other important risks are due to the timing and penetration assumptions. It is clear that if the technology benefits are slipped relative to the year of equipage, the benefits will be eroded quickly. Thus, the analysis indicates several variables that decision makers would need to investigate further before committing valuable resources.

Figure 9. Sensitivity Results



Conclusions

This paper has presented the ASAC Air Carrier Cost-Benefit Model and reported the results of a illustrative study to evaluate the benefits of a set of airport capacity enhancements. The CBM integrates an activity-based cost model of air carrier operating costs with a standard life-cycle cost model of equipment acquisition to evaluate the potential benefits of investment in aviation technology and infrastructure.

Our goal in evaluating the LVLASO technologies was to demonstrate the use of the CBM in conjunction with other ASAC models. Therefore, the results presented here should not be viewed as a definitive analysis of any NASA program element. In particular, this exercise was concerned exclusively with the costs and benefits associated with a large air carrier. To fully assess the potential benefits of a coordinated program such as LVLASO requires attention to other stakeholders in the national airspace system. Furthermore, our estimates of the potential benefits of LVLASO should be viewed as conservative for the reasons indicated.

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