Partnership for AiR Transportation
Noise and Emissions Reduction
An FAA/NASA/Transport Canada-
sponsored Center of Excellence

Protoype Work Plan for the Aviation Environmental Portfolio Management Tool

prepared by
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The authors express their appreciation to the individuals who reviewed drafts of this report, offering their thoughtful comments and expert counsel. Following careful examination, we addressed many of these suggestions in this final version. Other suggestions are being considered as part of ongoing development; we will address these suggestions in future documents. This inclusive process is inherent to PARTNER's mission and philosophy. It greatly contributes to the thoroughness of our research, enhancing accuracy, validity, and communication with a broad-based constituency.

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EXECUTIVE SUMMARY

The Federal Aviation Administration's Office of Environment and Energy (FAA-AEE) is developing a comprehensive suite of software tools that will allow for thorough assessment of the environmental effects of aviation. The main goal of the effort is to develop a new capability to assess the interdependencies between aviation-related noise and emissions effects, and to provide comprehensive cost analyses of aviation environmental impacts. The economic analysis function of this suite of software tools has been given the rubric Aviation Environmental Portfolio Management Tool (APMT).[1] This function will ultimately be derived from existing tools, tools currently under development, and new tools that must be developed.

FAA-AEE has provided a grant to the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER), an FAA/NASA/Transport Canada-sponsored Center of Excellence, to develop three documents describing APMT requirements, APMT architecture, and an APMT prototype work plan.

This APMT Prototype Work Plan is the third in the three-document series. The first document is the APMT Requirements Document, providing a detailed list of the functional requirements and guidance on implementation of APMT, with supporting background discussions to help place these requirements within the broader context of current practice. The APMT Requirements Document also defines the recommended time frames for development and use as well as the geographical and economic scope for analyses performed using APMT. The second document in the series is an APMT Architecture Study document that describes in detail the components of the APMT architecture, outlines the interfaces that will be required among those components, and establishes how APMT will interact with other tools that exist or are under development, including the Environmental Design Space (EDS)[2] and the Aviation Environmental Design Tool (AEDT)[3]. The Architecture Study also reviews existing tools available for these types of analysis, assesses their suitability for use in APMT, and establishes additional development that will be necessary to achieve APMT requirements.

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[1] Throughout this document, as is typical in environmental economic analysis, we will label changes in monetary flows in the aviation markets and the general economy as "costs" although it is recognized that they may be positive or negative. Similarly, we will label changes in health and welfare that occur through environmental pathways as "benefits" although they may be positive or negative.

[2] The Environmental Design Space (EDS) is a numerical simulation capable of estimating source noise and exhaust emissions, as well as performance and economic parameters for future aircraft designs under different technological, operational, policy, and market scenarios. EDS will also provide these parameters for existing aircraft designs when there is a need to simulate existing aircraft at a higher fidelity than exists in current tools. In addition, EDS will serve as a mechanism for collecting, incorporating, and quantifying long-term technology forecasts.

[3] The Aviation Environmental Design Tool (AEDT) is an integrated suite of FAA noise and emissions modeling tools, including the Integrated Noise Model (INM), MAGENTA, Emissions and Dispersion Modeling System (EDMS), and the System for Assessing Aviation Global Emissions (SAGE). AEDT takes detailed schedule and fleet information as input and provides noise and emissions inventories, both locally and globally.

This document is the APMT Prototype Work Plan. It describes in detail a one-year APMT prototyping effort that will identify gaps or weaknesses in the APMT architecture and stimulate advancements in development. In addition, the APMT Prototype Work Plan document delineates all of the entities necessary for the analyses, as well as their roles and data requirements, and provides a schedule of activities. The Prototype Work Plan also provides a brief discussion of the steps required to move beyond the APMT Prototype to APMT Versions 1 through 3, as described in the Architecture Study.

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LIST OF ACRONYMS

AEDT	Aviation Environmental Design Tool
AEE	Office of Environment and Energy
AERO-MS	Aviation Emissions and Evaluation of Reduction Options Modeling System
API	Application Program Interface
APMT	Aviation Environmental Portfolio Management Tool
CAEP	Committee on Aviation Environmental Protection
EDMS	Emissions and Dispersion Modeling System
EDS	Environmental Design Space
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FESG	Forecasting and Economic Analysis Support Group
JPDO	Joint Planning and Development Office
MAGENTA	Model for Assessing Global Exposure to Noise from Transport Aircraft
MAIPA	Multi-Attribute Impact Pathway Analysis
NASA	National Aeronautics and Space Administration

1 INTRODUCTION

This work plan describes the steps in the development of APMT to be carried out during the first year to yield an initial prototype. The work is organized around the development of several blocks and modules whose functions are described in detail in the APMT Architecture Study document. The APMT Prototype will be constructed to identify gaps or weaknesses in the APMT architecture and stimulate advancements in development of APMT. It is therefore our objective to construct all of the functional modules of APMT, although with more limited capabilities than planned for the final versions. This will enable us to test the functionality of APMT for addressing various policy questions. We will also assess and propagate uncertainties from the module level to the APMT system level to guide the determination of high priority areas for future development and refinement.

Before presenting the Prototype Work Plan, we begin with a brief description of the various APMT blocks and modules, as taken from the Architecture Study. The recommended APMT architecture is shown in Figure 1. APMT is composed of five functional blocks: the Partial Equilibrium Block simulates economic flows in the aviation market; the Aviation Environmental Design Tool (AEDT) Block converts aviation activity into quantities of emissions and noise distributed in time and space; the Benefits Valuation Block converts the quantities of emissions and noise to monetized health and welfare impacts (including broader socioeconomic and ecological effects); the General Economy Block evaluates the changes in economic flows in other markets due to changes in the aviation market; and the Analysis and Display Block allows the results to be analyzed graphically and provides quantitative estimates of uncertainty.

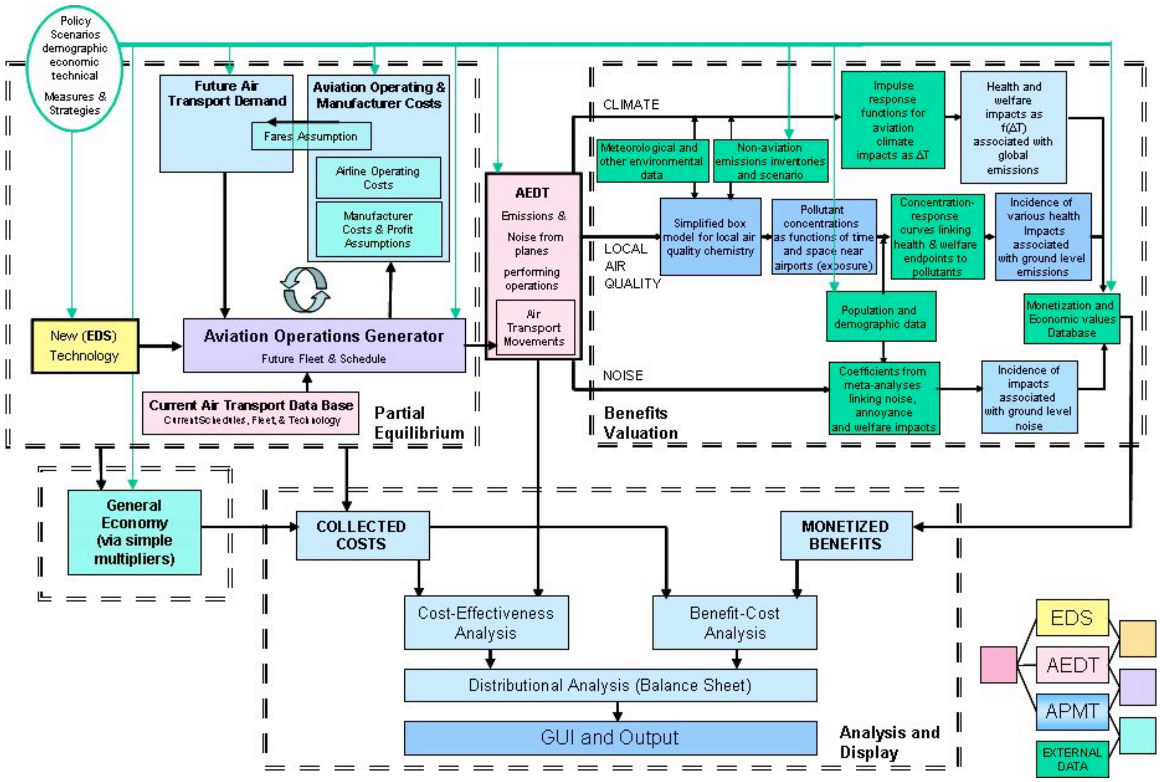

Figure 1: Overall APMT Architecture

These five blocks are described in greater detail below.

1) The **Partial Equilibrium[4] Block** takes estimates of future aviation demand and other assumptions specific to various policy scenarios, establishes a future fleet and flight schedule for input to the AEDT Block, and assesses manufacturer costs, operator costs, and consumer surplus.

   An assumption about the extent to which costs are passed on to consumers, leading to a modification of the initial demand assumption, completes the partial-equilibrium loop. Airline costs, manufacturer costs, and consumer surplus can be used directly for cost-effectiveness[5] and benefit-cost assessments[6], or can be

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[4] Partial equilibrium refers to analysis of change in one market, here the market for air transport, without taking under consideration how changes in one market imply changes in other markets. In the context of APMT, this means capturing the new equilibrium in the market for air travel after a change in policy, and the impact of that change on the traveling public and air carriers.

[5] Cost Effectiveness Analysis (CEA) is used to determine the outcome or impact of alternative regulatory choices. It is useful for answering the question: "Given several options for addressing an environmental problem through regulation—each (ideally) with similar benefits, which choice has the lowest costs?" Typically the benefits are defined using some surrogate for the ultimate environmental effect (e.g. kg NOx vs. incidence of adverse health effects).

[6] Benefit-Cost Analysis (BCA) seeks to determine the extent to which a policy option will produce a net benefit to society (independent of distributional aspects such as who wins and who loses). By estimating the net present value of benefits less costs relative to a well-defined baseline scenario, BCA can be used to

multiplied to reflect indirect and induced effects associated with broader effects in the general economy.

The Partial Equilibrium Block includes a link to the Environmental Design Space (EDS) to provide new technology aircraft that may be introduced as part of the policy scenario, as well as to ensure that the future aircraft provided by EDS are synthesized using assumptions and requirements consistent with the APMT scenario. To develop this functionality, an Aviation Operations Generator module will be developed in concert with AEDT. This module will be based upon methods used by the Wyle/FAA Model for Assessing Global Exposure from Noise of Transport Airplanes (MAGENTA), but modified to enable the introduction of new aircraft from EDS. Manufacturer cost and aircraft price estimates will be based upon correlations drawn from regression analyses of historical price data with a range of assumptions for manufacturer profits. Uncertainty will be addressed through parametrically varying the estimates. Higher fidelity modeling of manufacturing costs associated with technology trade-offs will be accomplished using the NASA/GaTech Aircraft Life Cycle Cost Analysis code (ALCCA), but further assessment and development of ALCCA will be required.

Airline operating costs will be estimated using the Dutch Aviation Emission and Evaluation of Reduction Options Modeling System Aviation Operating Cost Model (AERO-MS ACOS) or similar modeling techniques. Airline cost pass-through to fares will be modeled parametrically in a manner similar to that done within AERO-MS, although work to improve these techniques is recommended for longer-term application within APMT.

2) The **Aviation Environmental Design Tool (AEDT) Block** represents the significant development efforts already underway within the FAA to integrate the existing noise and emissions modeling tools, including the Integrated Noise Model (INM), MAGENTA, Emissions and Dispersion Modeling System (EDMS), and the System for Assessing Global Aviation Emissions (SAGE).

   In aggregate, AEDT will take as input the detailed schedule and fleet information from the Partial Equilibrium Block, and will provide as output the noise and emissions inventories, both locally and globally. These outputs may be used directly with the costs from the Partial Equilibrium Block to form cost-effectiveness assessments, or can be passed to the Benefits Valuation Block to enable benefit-cost assessments.

3) The **Benefits Valuation Block** takes noise and emissions inventory information from the AEDT Block, demographic and socioeconomic data, measurements of background concentrations of pollutants (e.g. those provided by the US EPA), and estimates of changes in health and welfare endpoints for climate, local air quality and noise. To a large extent, this is accomplished through reliance on external

determine the degree to which a policy scenario improves economic efficiency. BCA requires that benefits and costs be expressed in the same units (typically monetary). It is the recommended basis in North America and Europe for assessing policy alternatives.

sources of information (e.g. concentration-response curves established by other agencies for relating pollutants to mortality and morbidity incidences).

Changes in health and welfare are then monetized to enable benefit-cost analyses. The monetization will draw heavily on a wide range of published studies within the U.S. and Europe that have focused on this topic. The block should be developed starting from the existing capabilities of the MIT Multi-Attribute Impact Pathway Analysis tool (MAIPA), but should be augmented to include components of the US EPA Environmental Benefits Mapping and Analysis Program (BenMAP).

4) The **General Economy Block** is currently envisioned as a simplified mechanism for including multiplier effects associated with indirect and induced costs in markets beyond the primary aviation markets. These multiplier effects will be specified exogenously and drawn from the literature as well as from external general equilibrium[7] models. However, future versions of APMT may consider a more complete integration of a general equilibrium model with the other components of APMT.

5) The **Analysis and Display Block** will collect the costs and benefits, provide assessments of propagated uncertainty, and allow cost-effectiveness and benefit-cost analyses. Depending on the level of maturity of the modeling tools and the specific assessment scenario being studied, varying types of distributional analyses[8] will be available. For example, for the cost-effectiveness analysis it will be possible to understand the effects of policy scenarios on broad geographical regions and primary market categories. For the benefit-cost assessments, it will be possible to consider a variety of categories of impacted populations consistent with the level of detail present within the census data.

Work must start immediately on all of these blocks to meet near-term and mid-term needs for policy guidance. It is anticipated that the first version (years 1-3) of APMT will include the Partial Equilibrium Block, the Aviation Environmental Design Tool (AEDT) Block, and the Analysis and Display Block, thus enabling only cost-effectiveness analyses. APMT Version 2 will incorporate the Benefits Valuation Block, providing a first capability for benefit-cost assessment. However, it is expected that due to limited data availability, the Benefits Valuation Block will be restricted initially to application within the U.S. (years 1-3), with expansion to other parts of the world enabled later through international partnerships (years 4-6) where data are available. APMT Version 3 will incorporate the General Equilibrium Block and improvements to the other model components (years 3-8).

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[7] General equilibrium analysis explicitly models relationships and feedback amongst industries that are related as suppliers and demanders of intermediate goods.

[8] Distributional analyses seek to determine the segments of the economy that will gain or lose as a result of a policy option. The segments of the economy may be defined by markets, components of markets, or specific parts of the population as defined by demographic information or geographical location.

2 APMT PROTOTYPE SCHEDULE

The overall schedule for the development of the APMT Prototype assumes a work plan start date of January 1, 2006. The first prototypes for each component are planned to be complete by the end of May 2006 to allow time for integration and testing within the first year. In following years, work will focus on the development of APMT Versions 1-3. The individual tasks, schedules, and milestones for each component module are described below, but an overall view of the program schedule can be found in Figure 2.

Module	Tasks	2006 (Jan–Dec)
Aviation Operations Generator Module	Provide database definition for current AEDT replacement aircraft database	
	Provide database definition for current AEDT retirement aircraft database	
	Determine categorization scheme for airlines	
	Determine table structure for airline categories data table	
	Define aircraft retirement database and implementation scheme	
	Define replacement database and implementation scheme	
	Software implementation of airline and/or airline category based aircraft retirement approaches	Beta Final
	Software implementation of airline and/or airline category based aircraft replacement approaches	Beta Final
Fleet Selection	Conduct research and gather data on airline fleet selection decisions	
	Develop a methodology to capture fleet selection process	
	Create a prototype fleet selection implementation	
	Use the fleet selection module within the larger APMT environment including sensitivity analyses to to determine fidelity required for future implementations	
Manufacturer Costs / Aircraft Prices Module	Obtain aircraft price databases and create regression based price model	
	Benchmark regression-based price model and carry out parametric sensitivity studies	
	Define sample problem involving Nox prototype problem for a 777-class aircraft	
	Modify regression model to account for the effects of new technology introduction	
	Combine regression-based model with different profit scenarios	
	Carry out parametric sensitivity studies to assess fidelity of model	
	Complete a preliminary version of the Manufacturer Costs/Aircraft Prices software module	
	Determine fidelity required to distinguish between policy scenarios through parametric sensitivity studies of system-level outcomes to aircraft price and manufacturer cost estimates. Provide a brief report.	
	Analyze the sample problem. Provide a report on the analysis.	
	Synthesize results and develop plan for future development needs. Provide a report.	
Air Carrier Cost	Teaming with AERO-MS developers. (Complete subcontract with MVA by January 10, 2006)	
	Begin design of the Partial Equilibrium Block. Deliver draft design document.	
	Detailed air carrier cost module design. Provide jointly detailed design report.	
	Development of prototype air carrier cost module. Provide software module for integration into APMT prototype.	
	Use the airline operating costs module to determine high priority development needs. (Provide a report and work plan for further development of airline operating costs module)	
Air Carrier Fares Module	Characterize constant rate of return approach for the team who will weave the modules together. (Provide a report on the recommended approach and software implementation)	
	Review existing pricing/fares literature. (Provide a brief report)	
	Brief report providing recommendations for improved methods for modeling fares.	
Demand Module	Range of single own-price demand elasticity estimates. (Provide a brief report containing estimates)	
	Table of elasticities by flight characteristics (international vs. domestic, etc.)	
	Assess weaknesses in the available estimates from literature as areas for future research. (Provide a brief report)	

Figure 2. APMT Prototype Work Plan Schedule (page 1 of 2)

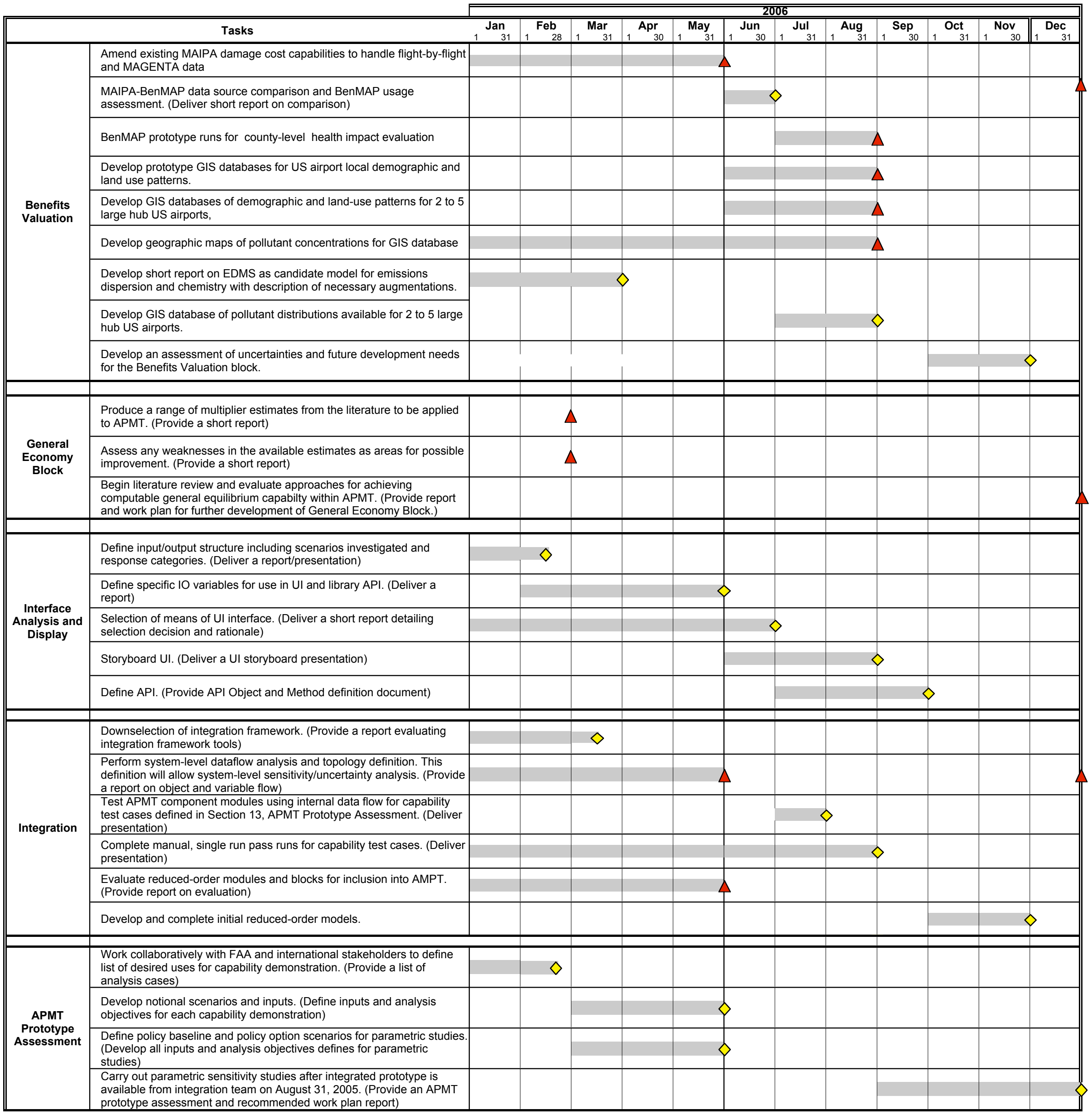

Figure 2. APMT Prototype Work Plan Schedule (page 2 of 2)

3 AVIATION OPERATIONS GENERATOR MODULE

The Aviation Operations Generator module, to be used within the APMT Partial Equilibrium Block, will leverage work done for the FAA Office of Environment and Energy within the AEDT development program. Wyle Laboratories has been working to modify MAGENTA under that initiative, including the creation of an independent "forecasting processor" module to generate a future fleet mix. This work is expected to be completed by January 2006, enabling APMT to make use of this independent module in its prototype implementation in the next year.

The MAGENTA forecasting process, however, is designed to reflect only typical retirement and phase-out schedules and does not capture the trade-offs involved in the selection of a fleet. Thus, introducing new aircraft types with this module is simply a matter of adding the new aircraft to the database in the year they become available and allowing them to enter the fleet according to a retirement schedule. EDS will be an important element in defining the new aircraft in the databases, as well as defining their date of availability and their expected introduction rate. However, this approach may not be sufficient if a choice of replacement aircraft exists, since all vehicles retired within a particular class are replaced by the same aircraft under the current MAGENTA approach.

In order to capture the economic decisions involved in choosing a fleet, a replacement mechanism beyond that available in MAGENTA will be developed (as described further in Section 4), and some changes to the MAGENTA process will also be needed. The external mechanism should be able to capture a selection process among replacement aircraft with different operating costs (e.g. fuel burn, speed) and price characteristics, thus establishing a link to the Airline Operating Costs module. In order to reflect the fact that not all airlines may choose the same fleet replacement strategies, MAGENTA will have to be modified to allow for multiple replacement curves and aircraft replacement databases, each applying only to a subset of the fleet, divided by airline or airline type (e.g. major, start-up, regional). The user-defined substitutions currently allowed by MAGENTA will not fulfill this role since they are applied prior to the replacement/retirement process.

The work on the Aviation Operations Generator module will be completed by staff from Wyle Laboratories, but with guidance and coordination provided from other members of the APMT team.

3.1 Schedule and Milestones

The schedule and milestones for this part of the prototype development are shown below.

- Provide the database definition for the current AEDT replacement aircraft database (*Complete by January 20, 2005*)
- Provide the database definition for the current AEDT aircraft retirement database (*Finish by January 20, 2005*)
- Determine categorization scheme for airlines (*To be received by February 15, 2006*)

- Determine table structure for airline categories data table (*Complete by February 28, 2006*)
- Define aircraft retirement database and implementation scheme (*Finish by March 15, 2006*)
- Define aircraft replacement database and implementation scheme (*Finalize by March 15, 2006*)
- Software implementation of airline and/or airline category based aircraft retirement approach (*Finish beta version by April 31, 2006. Finish final version by May 31, 2006*)
- Software implementation of airline and/or airline category based aircraft replacement scheme (*Finish beta version by April 31, 2006. Finish final version by May 31, 2006*)

4 FLEET SELECTION

As described in Section 3, modifications made to the Aviation Operations Generator module will not be sufficient to capture the decision-making involved in the selection of one aircraft over another by an airline under different policy, market, and technology scenarios. Therefore, a fleet selection mechanism will be developed as part of APMT. The details of this mechanism have not yet been determined; during the first year, we will research various options and develop an initial fleet selection capability for implementation in the APMT Prototype. At the end of the first year, we will provide a detailed definition of fleet selection module for future versions of APMT.

The research to support the definition of the fleet selection mechanism will be led by MVA, but will draw upon expertise and work carried out previously by other team members as appropriate. In particular, MITRE has created the Market FX model, an agent-based approach for simulating aviation market behavior. However, the Market FX model itself is unlikely to be suitable for inclusion in APMT due to long execution times. In addition to the MITRE expertise, the Georgia Institute of Technology (Georgia Tech) has been carrying out work in the product selection area that will also be relevant to this portion of the APMT Prototype. Finally, Dr. Belobaba at MIT has developed a simplified spreadsheet-based fleet selection model as a component of the MIT/Cambridge University Silent Aircraft Initiative. This may be a useful starting point on which to build.

Since forecasting of future demand is taken as an input in this phase of APMT development, caution will be exercised to ensure that the assumptions under which a scenario fleet is generated do not conflict with the assumptions used in the input demand forecasts. It is essential to ensure consistency between the Future Air Transport Demand module, the Aviation Operations Generator module, and the input forecasts from Forecasting and Economic Support Group (FESG), a CAEP sub-group.

This work will be led by MVA, working closely with a student from Georgia Tech, and coordinating more generally with MIT and MITRE-CAASD.

4.1 Schedule and Milestones

In developing the prototype for the fleet selection mechanism, the APMT team will use the following schedule.

- Conduct research and gather data on airline fleet selection decisions (*Deliver presentation to APMT developers on information collected by January 31, 2006*)
- Develop a methodology to capture the fleet selection process (*Deliver presentation to APMT developers on methodology by February 28, 2006)*
- Create a prototype fleet selection implementation (*Complete prototype module by May 31, 2006*)
- Use the fleet selection module within the larger APMT environment, including sensitivity analyses to determine fidelity required for future implementations (*Finish report defining the fleet selection mechanism for future APMT versions and work plan for further development of the fleet selection module by December 31st, 2006*)

5 MANUFACTURER COSTS/AIRCRAFT PRICES MODULE

The Manufacturer Costs/Aircraft Prices module must provide the prices of all aircraft to be considered in the Aviation Operations Generator module and the Airline Operating Costs modules, including estimates of prices for new technology aircraft. It must also provide estimates of the impacts on manufacturer costs.

Activities in the first year will focus on the following: (1) establishing a regression-based price model using existing database information; (2) carrying out a sample problem; (3) using results from the sample problem to establish the required level of fidelity for the module and make recommendations regarding development in subsequent years. This work will be conducted by MIT researchers. Work within EDS is also planned, focusing on bottom-up cost estimation approach using ALCCA. Depending on the status of this EDS work, it may provide additional guidance on the development of the Manufacturer Costs/Aircraft Prices module for APMT.

5.1 Regression-based Price Models

Predictive models for aircraft price will be created using a methodology based on a regression of aircraft characteristics. Existing aircraft databases will be identified, collected, and used to create a model that determines the market value of the aircraft based on a relevant set of characteristics (e.g. aircraft range, payload capacity, speed, fuel efficiency, etc.). These aircraft databases may have to be purchased from commercial vendors (e.g. the Airliner Price Guide). The price model will be benchmarked against similar models that have appeared in the open literature. A set of parametric studies will be carried out to assess the sensitivity of price predictions to regression parameters and input data.

5.2 Sample Problem

A sample problem will be defined and used to assess and further develop the components of the Manufacturer Costs/Aircraft Prices Module. The proposed sample problem is the NOx prototype problem, which is being used in EDS and AEDT development. Aircraft price and manufacturer cost impact estimates will be made in the context of this sample. The work in the first year will focus on a single vehicle, a 777-class aircraft.

The simplified regression-based price model will be modified to account for the effects of new technology introduction. This price model will be combined with different profit scenarios to provide estimates of a ceiling on manufacturer costs. These cost impacts will be compared with external estimates, where available. The fidelity of the models will be assessed by parametric sensitivity studies in which key parameters are varied.

5.3 Synthesis and Recommendations

A detailed study will be carried out using the results from the sample problem, with the goal of establishing the required level of fidelity for the Manufacturer Costs/Aircraft Prices Module. The aircraft price and manufacturer cost estimates will be combined with other APMT module outputs and propagated to the APMT system level. Parametric studies will then be carried out to determine the sensitivity of system-level outcomes to aircraft price and manufacturer cost estimates, which will help to determine the level of fidelity required at the module level in order to distinguish between different policy scenarios. Future development needs for the module will be established.

The development of additional component-level cost prediction capabilities will be required for assessing some aspects of cost impacts that are not captured by high-level price regressions (e.g. changes in technology that do not directly influence fuel burn or weight, such as the incorporation of new technology combustors). Such an approach is being pursued within EDS and we expect to incorporate some lessons learned from this activity in future APMT development efforts.

MIT will lead this component of the work plan.

5.4 Schedule and Milestones

The schedule and milestones for this part of the prototype development are shown below.

- Obtain aircraft price databases and create regression-based price model (*Complete price model by January 31, 2006*)
- Compare regression-based price model against other available models. Carry out parametric studies to determine the sensitivity of price predictions to regression parameters and input data. (*Finish regression-based price model as well as associated fidelity/sensitivity assessments by February 28, 2006)*
- Define aircraft price/manufacturer cost sample problem involving the on-going AEDT NOx prototype problem for a 777-class aircraft (*Define sample problem by February 2006*)
- Modify regression model to account for the effects of new technology introduction (*Complete modified regression model by March 31, 2006*)
- Combine regression-based model with different profit scenarios to provide estimates of a ceiling on manufacturer costs, and compare with external estimates

where available (*Deliver combined model as well as comparison with external estimates by April-May 2006*)

- Carry out parametric sensitivity studies to assess the fidelity of the model (*Complete by May 31, 2006*)
- Complete a preliminary version of the Manufacturer Costs/Aircraft Prices Module suitable for analysis of 777-class aircraft (*Finish software module by May 31, 2006*)
- Determine the level of fidelity required to distinguish between different policy scenarios through parametric sensitivity studies of system-level outcomes to aircraft price and manufacturer cost estimates (*Provide a brief report on the fidelity determination by June 30, 2006*)
- Analyze the sample problem (*Provide a report on analysis of the sample problem by August 31, 2006*)
- Synthesize the results of the sample problem into a statement of module fidelity requirements, an assessment of current modeling capabilities, and a plan for future development needs, including the extension of the module for other aircraft classes (*Provide a report that includes: detailed documentation of the model, results of the sample problem, and a plan for future development needs by Dec 31, 2006*)

6 AIRLINE OPERATING COSTS MODULE

The primary objective of the Airline Operating Costs module is to estimate *aircraft* operating costs and how they might change under different policy scenarios. However, we refer more broadly in this section to *airline* operating costs because APMT must have the capability to estimate cost impacts under alternative future airline network, fleet, and operating environments. As air travel demand, competitive conditions, and fuel prices change, characteristics of the air transportation system can change dramatically, including fleet composition (e.g. aircraft sizes), network characteristics (e.g., hub-and-spoke vs. point-to-point flights) and airline operations (e.g., stage length and daily aircraft utilization). These airline-related characteristics should be captured by APMT, in addition to the actual impacts on aircraft operating costs of new policies, regulations, and/or technologies.

The air travel demand forecasts and airline supply responses generated by the Aviation Operations Generator module of APMT provide input to both the Airline Operating Costs module and the AEDT Block. For the purposes of calculating airline operating costs, the detailed capabilities of AERO-MS, specifically the Aviation Operating Cost Model (ACOS) module, are closely suited to the requirements of APMT. Therefore, MVA will lead the development of ACOS+, a model based on the AERO-MS methodologies, but specifically suited for incorporation in APMT.

The Aviation Operating Cost Model (ACOS) of AERO-MS performs detailed calculations of airline operating costs under different scenarios. The airline operating costs framework used by ACOS is quite detailed and compatible with the cost categorization schemes in US DOT Form 41. AERO-MS combines these cost components into measures of variable operating cost per unit of capacity, and these measures can be reported by flight stage, aircraft type, aircraft function (e.g., passenger, freighter), and aircraft technology level. Airline operating cost results can also be reported by spatial definitions of up to 14 world regions, in line with IATA regional definitions.

This component of the APMT Prototype Work Plan will be led by MVA. MVA will also have overall responsibility for the Partial Equilibrium Block, including the design of how ACOS+ and other components will be functionally integrated; these other components will include EDS, the Aviation Operations Generator module, the Manufacturer Costs/Aircraft Prices module, the Fares Assumptions module, and the Future Air Transport Demand module.

6.1 Schedule and Milestones

The schedule and milestones for this part of the prototype development are shown below.

- Teaming with AERO-MS developers (*Complete subcontract with MVA by January 10, 2005)*
- Design of the Partial Equilibrium Block and development of design report describing the Partial Equilibrium Block. Design Document contains details of the algorithms to be applied, the proposed modular structure of the software to implement the algorithms, the data structures in the form of tables of "public" data from the model (inputs expected, outputs to be produced, and their dimensions), and a discussion of software platform and output format (*Provide draft of design document by January 31, 2006*)
- Develop detailed design of Airline Operating Costs module, including input and output requirements, functionality, and multi-year development plan (*Provide a detailed design report by February 15, 2006*)
- Development of a prototype Airline Operating Costs module (*Provide software module for integration in APMT prototype by May 31, 2006*)
- Use the Airline Operating Costs module within the larger APMT environment, including sensitivity analyses to determine high priority development needs for APMT (*Provide a report and work plan for further development of Airline Operating Costs module by December 31st, 2006)*

7 FARES ASSUMPTIONS MODULE

The prototype of the Fares Assumptions module will operate by adjusting fares to maintain an existing rate of return. That is, if costs are predicted to increase by a certain percentage, fares will rise by the same percentage to maintain a proportional relationship. This percent change in fares will then be passed to the Future Air Transport Demand module. Because the Future Air Transport Demand module requires the percent change in fares, no data on average fares are necessary. Additionally, no assumptions need to be made about the magnitude of the existing return; proportional adjustments will maintain the level of return. This functionality will represent a placeholder for a future fare capability that will be capable of differentiating across market characteristics (including, pending further development, drawing on differentiated elasticities in an expanded Future Air Transport Demand module).

Simultaneous to beginning work on fares for the prototype, as described above, research will begin to refine the Fares Assumptions module to offer a more realistic approach that takes into account the nature of competition. This work will build on a literature review focusing on the nature of competition and fares. It is expected that a model will be made up of structural equations that depend on segment elasticities, cross-carrier elasticities, segment concentration, and other market characteristics that can be empirically estimated using econometric techniques.

MVA and MITRE-CAASD will conduct this work and draw on other economic expertise in FAA, PARTNER, and academia. MITRE-CAASD has access to the data sources that will be required for estimation of the fares module (Database 1B, the T100 database, metropolitan area statistics, etc.). Both the early capability and the more advanced capability will have to be developed with consideration of both the Future Air Transport Demand and Airline Operating Costs modules. Application of the new Fares Assumptions module will depend on any decisions to differentiate the different data sets by carrier or carrier types.

7.1 Schedule and Milestones

The schedule and milestones for this part of the prototype development are shown below.

- Characterize the constant rate of return approach (*Provide a report on the recommended approach and software implementation by February 1, 2006)*
- Review existing pricing/fares literature (*Provide a brief report summarizing the literature by March 1, 2006*)
- Write a brief report providing recommendations for improved methods for modeling fares (*Deliver report by December 1, 2006)*

8 FUTURE AIR TRANSPORT DEMAND MODULE

The function of the Future Air Transport Demand module is to provide adjustment to the levels or growth rates in the Aviation Operations Generator module that represent the demand response to rising or falling fares. The forecast uptake and processing will be handled in the Aviation Operations Generator module, which will be based on the MAGENTA capability for processing FESG forecasts. The most straightforward way to reflect demand response to fares for the prototype is to use a single mean-own-price demand elasticity estimate based on estimates from AERO-MS and from the literature. This elasticity estimate will then be multiplied by the predicted percent-change in average fares from the Fares Assumptions module, and the resulting percent-change in passengers will be uniformly applied to the Aviation Operations Generator module. This will be sufficient to demonstrate how to connect the modules in the Partial Equilibrium Block, although a future capability should differentiate elasticities by segment length and other characteristics and possibly use an elasticity distribution to reflect uncertainty.

To be capable of connecting with the general equilibrium module, the module will need to contain other elasticities, including income elasticity of air travel demand, in order to track the feedback effects from the general economy through the aviation market. Alternatively, the general equilibrium feedback can be passed directly to the Aviation Operations Generator module.

This work will be led by MITRE CAASD, who will collaborate with MVA on the task.

8.1 Schedule and Milestones

The schedule and milestones for this part of the prototype development are shown below.

- Produce a range of single own-price demand elasticity estimates based on the existing literature (*Provide a brief report containing these estimates by February 1, 2006)*
- Produce a table of elasticities by flight characteristics (international v. domestic, etc.) (*Provide the table by February 1. 2006)*
- Assess any weaknesses in the available estimates from the literature as areas for possible future research (*Provide a brief report containing assessment by May 31, 2006)*

9 BENEFITS VALUATION BLOCK

In the first year of development for the Benefits Valuation Block, existing MIT Multi-Attribute Impact Pathway Analysis (MAIPA) capabilities for estimating damage costs related to noise, air quality, and climate impacts will be amended to handle AEDT flight-by-flight movement data and inventories. Improvements to MAIPA databases will also be executed, including the addition of alternative airport-by-airport operational data generated for use with MAGENTA. This will allow a fully-functional, basic valuation methodology to be operational within the first six months after initiation of the work plan.

Two follow-on activities will run in parallel. The first of these activities is to assess BenMAP as a replacement for the concentration-response-valuation capability in MAIPA used for air quality evaluations. Use of BenMap would improve APMT by allowing the evaluation of health impacts using the latest epidemiological research assessed by the U.S. EPA for use in policy analyses. The process for incorporating BenMAP will initially require a thorough comparison of MAIPA and BenMAP data sources, followed by an assessment of how BenMAP could be used to accept emissions inventories provided by AEDT (including prototype runs).

The second activity is to assess the mechanics of producing 2-D surface exposure maps detailing pollutant concentrations and noise contours for each of the MAGENTA Shell-1 airports. Use of 2-D maps would enhance APMT by improving the fidelity of the population exposure estimate and would potentially allow the inclusion of a wider range of BenMAP functionality within the APMT architecture. Incorporating higher fidelity surface exposure maps would require that population and land use maps for each airport be developed using GIS capabilities, and that modifications be made to the current assumptions in MAIPA for estimating pollutant concentrations as functions of time and space. For emissions, these modifications would include implementing a dispersion model accounting for average winds and pollutant chemistry. EDMS is the desired model through which to develop pollutant maps. However, some modification/augmentation of methods currently used within EDMS will be required.

The work team for this effort will be established and directed by MIT and will require close collaboration with the Wyle MAGENTA development team, the CSSI EDMS development team, and an outside expert in the creation and analysis of unique GIS databases.

MIT will lead this component of the work plan.

9.1 Schedule and Milestones

The schedule and milestones for this part of the prototype development are shown below.

- Amend existing MAIPA capabilities for estimating damage costs to allow use of AEDT flight-by-flight movement data and inventories and additional MAGENTA airport-by-airport operational data (*Deliver new MAIPA version, compatible with AEDT, by June 1, 2006*)
- Complete MAIPA-BenMAP data source comparison and BenMAP usage assessment (*Deliver short report on MAIPA-BenMAP data source comparisons by June 30, 2006*)
- Develop BenMAP prototype runs for county-level health impact evaluation (*Complete BenMap prototype runs by September 1, 2006*)
- Develop prototype GIS databases for U.S. airport-local demographic and land-use patterns (*Construct GIS database prototype by August 31, 2006*)
- Develop GIS database of demographic and land-use patterns available for 2-5 large hub U.S. airports (*Complete GIS database by September 1, 2006*)
- Develop geographic maps of pollutant concentrations around airports (*Provide maps by August 31, 2006*)
- Develop short report on EDMS as candidate model for emissions dispersion and chemistry with description of necessary augmentations (*Finish the report by March 31, 2006*)
- Develop GIS database of pollutant distributions available for 2-5 large hub U.S. airports (*Provide database by September 1, 2006*)
- Complete an assessment of uncertainties and future development needs for the Benefits Valuation Block (*Finish the report by December 1, 2006*)

10 GENERAL ECONOMY BLOCK

As described in the APMT Requirements Document, initial development of the General Economy Block will consist of the application of simple multiplier effects. The most basic form this can take is the application of a single economy-wide multiplier, but drawing on a more detailed input-output framework will allow for a greater degree of distributional analysis without significantly greater difficulty in development. This approach will use the output of the Partial Equilibrium Block (the change in output of carriers and manufacturers measured in dollars) as its primary input. It will be tied to the Future Air Transport Demand module using income elasticities. The scale of this work is comparable to that of the prototype Future Air Transport Demand and Fares Assumptions modules in that it primarily consists of application of carefully researched parameters.

Work in the first year will also include steps toward the identification and/or development of a computable general equilibrium model calibrated to match the FESG growth rates as closely as possible. Over time, maturity of the General Economy Block may depend on treating the other components as "nested" within the general equilibrium framework.

MITRE-CAASD has staff expertise in this area and will lead this work, drawing on expertise at MIT. This work will not take priority over the components of the Partial Equilibrium Block since the General Economy capability is not anticipated to be available for use until later in the development timeline. However, it is important that we assess this functionality as part of assessing the overall APMT architecture.

10.1 Schedule and Milestones

The schedule and milestones for this part of the prototype development are shown below.

- Produce a range of multiplier estimates from the literature to be applied to APMT (*Provide a short report containing these estimates by March 1, 2006*)
- Assess any weaknesses in the available estimates as areas for possible improvement (*Provide a short report containing this assessment by March 1, 2006)*
- Begin literature review and evaluate approaches for achieving a computable general equilibrium model capability within APMT (*Provide a report and work plan for further development of General Economy Block by December 31st, 2006)*

11 INTERFACE, ANALYSIS, AND DISPLAY

The broad applicability of APMT warrants the development of a graphical or forms-based user interface (UI) for ease of use. However, a library format with an accessible Application Program Interface (API) is still necessary so that various post-processing and further analysis tasks can take place. Simple analysis tasks should be possible without resorting to an arcane command line interface. This should also include any necessary visualization capabilities. Development of this graphical user interface requires workflow definitions and storyboarding for all possible combinations of user actions that are required.

The implementation of the user interface can take place simultaneously with the APMT analysis framework because, with the appropriate tools, the user interface development can create simplified "empty shells" that possess the final look and feel and allow for user interaction. Meanwhile, the APMT development and integration can take place in parallel. Once functional APMT prototype modules are complete, they can be integrated with the graphical user interface. Integration with the graphical user interface is not planned during the one-year prototyping effort.

Development of the UI will be coordinated with the AEDT development effort, specifically concerning look and feel and means of implementation. This does not mean that APMT must have a UI that is based upon that of AEDT, but rather that AEDT users must be able to recognize and understand the basic APMT UI. However, AEDT's current UI development schedule does not allow meeting the goals of the APMT UI prototype. Therefore, the APMT UI development must follow its own schedule.

Georgia Tech will lead the development of this module working closely with other team members.

11.1 Schedule and Milestones

The schedule and milestones for this part of the prototype development are shown below.

- Define Input/Output structure, including scenarios investigated and response categories *(Deliver a report/presentation to APMT Development Team by Feb 15, 2006*)
- Define specific I/O variables, for use in UI and Library API: Object & Variable listing (*Deliver a report to the APMT development team by May 31, 2006*)
- Select means of UI interface, e.g., application, web service, etc. (*Provide a short report regarding the selection decision and rationale by July 1, 2006*)
- Storyboard UI *(Deliver a UI storyboard presentation to APMT development team and UI developers by August 31, 2006*)
- Define API (*Provide API Object & Method definition documentation to APMT developers by September 30, 2006*)

12 INTEGRATION

The APMT framework as developed in the APMT Architecture Study document consists of a number of discrete blocks and modules that require linking and integration. In some areas, this also requires feedback loops and subsequent solution convergence. Therefore, consideration of the integration framework is critical. Any integration environment or framework must be capable of providing several basic capabilities:

- Allow integration of disparate modules over which the developers may not have source control
- Provide transparency of feedback loops for auditing and acceptance
- Allow inclusion of large and potentially disparate data sets
- Allow inclusion of future capabilities without significant additional development effort
- Facilitate development and distribution of both the API library and standard user interface

Because of these requirements, the selection of the integration framework for APMT must be considered on its own merits. It is not critical that the framework be identical to that of AEDT. However, AEDT, or a reduced-order representation of AEDT, must be compatible with the APMT framework.

A review of existing frameworks and tools that facilitate the integration of various modules will be completed. The possible choices range from standard programming languages to high-level graphical integration tools. The review will consider a range of criteria. First and foremost, it is important to consider the original design purpose of each tool, which may not fully coincide with the requirements for APMT. Another important characteristic that will be considered when reviewing possible frameworks is the ability to integrate existing code, or code pieces taken from existing tools, as necessary. Furthermore, there should also exist a capability to simply script and execute an existing analysis tool and extract the necessary information for the APMT analysis framework.

It will also be necessary to understand the capabilities of the various tools with regard to database connectivity because of the potentially large data sets required within APMT. This is especially critical if significant portions of the AERO-MS tool are included in APMT since AERO-MS is highly data-driven. It may be possible to incorporate components of the database used within the AERO-MS framework. The AERO-MS framework also includes various tools to ensure database integrity and facilitate merging and cleanup of various data sources into a unified database.

Another criterion for judging the suitability of the different integration frameworks and tools is the general ease of use as defined by how much of the functionality is accessible through a UI. This can range from pure text-based programming to high-level graphical frameworks. Additionally, it should be possible to create a customized UI for the end user by allowing UI development. The final form of delivery to, and execution by, the end user should be possible without a steep learning curve and significant expense. It is therefore important that a standalone application can be created or, alternatively, a free or low cost end-user form is available.

Finally, the overall availability and cost of the framework is to be considered. This can range from no cost to a significant expense.

Additional consideration must be given to the incorporation of AEDT and other functional blocks and modules into the APMT framework. AEDT, the Benefits Valuation Block, EDS, and other components are themselves large and computationally-intensive applications. Providing detailed results with full inventories will require prohibitive amounts of computational effort. This is undesirable if feedback and equilibrium loops are included. Therefore, it is also necessary to develop and incorporate reduced-order forms of these components within the APMT framework. The level of fidelity necessary must be assessed prior to development. This task will be performed in conjunction with the overall APMT fidelity and uncertainty assessment.

Georgia Tech, MIT, and MVA will work jointly to assess and select an integration framework. Implementation will be led by Georgia Tech.

12.1 Schedule and Milestones

The schedule and milestones for this part of the prototype development are shown below.

- Select an integration framework, dependent on format of APMT subcomponents (*Provide a report evaluating integration framework tools to APMT developers by March 15, 2006*)
- Perform system-level data-flow analysis and topology definition. A data-flow, analysis topology definition will allow system-level sensitivity/uncertainty analysis. (*Provide a report on object and variable flow to APMT developers by May 31, 2006*)
- Test APMT Component modules using internal Data Flow for capability test cases defined in Section 13, APMT Prototype Assessment (*Delivery of presentation to APMT developers and sponsors by July 31, 2006)*
- Complete manual, single pass runs for capability test cases (*Delivery of presentation by August 31, 2006*)

- Evaluate reduced-order modules and blocks for inclusion into APMT (*Provide report on evaluation by May 31, 2006*)
- Develop initial reduced-order models (*Complete reduced order models by Nov 30, 2006*)

13 APMT PROTOTYPE ASSESSMENT

Following the integration of modules to form the APMT Prototype, significant effort will be required to perform a rigorous assessment of the integrated functionality and the functionality of each module. Initially, the objective of the assessment will be to identify gaps in functionality that significantly impact the achievement of APMT requirements. In this way, the outcome of initial assessment efforts will be to identify high-priority areas for further development. Ultimately, the assessment effort will provide quantitative information on the performance of the final integrated APMT toolset relative to fidelity requirements.

In the first year, assessment of the APMT Prototype will be accomplished through two activities. The first will be a capability demonstration. The second will be a formal parametric sensitivity study and uncertainty assessment. The output of these two activities will be a detailed work plan for further development of APMT.

13.1 Capability Demonstration

The capability demonstration will be completed by identifying several desired uses for APMT (e.g. consideration of increased certification stringency, consideration of market-based measures, assessment of the influence of increased fuel price on health and welfare costs, etc.) and exercising the tool for these test cases to assess functionality.

The questions to be answered by this exercise include:

- Are the appropriate economic flows to analyze the test case represented in the APMT prototype?
- Are the modules internally self-consistent in their representation of the analysis scenario?
- Are the assumptions among the various modules consistent with one another for each of the analysis scenarios?

In performing the capability demonstration we will *not* seek to "answer" the sample analysis problems. The purpose will be to assess whether the appropriate economic and environmental behaviors and impacts are represented in a consistent way. Thus we may use representative notional data and notional policy and market scenarios where it is convenient to do so. However, we will assess if trends and overall levels of magnitude are consistent (given the assumptions). Ultimately we must address the question of whether or not the demonstrated functionality of APMT will offer an improvement over current practice (albeit subject to further development).

13.2 Parametric Sensitivity Study and Uncertainty Assessment

The parametric sensitivity study and uncertainty assessment will be accomplished by first defining a policy baseline scenario and an alternative policy option scenario. We will perform a benefit-cost assessment for the policy option relative to the baseline. We will then parametrically vary each of the key input parameters and many of the key modeling assumptions to enable us to determine the impact of each of these on the benefit-cost assessment. In particular, this analysis will allow us to quantify how sensitivity to input parameters and modeling assumptions translates into uncertainty at the level of APMT outputs. Here, too, the focus will not be on "getting the right answer" for the policy option, but rather on understanding how various inputs and assumptions at the module level influence system-level APMT results. Thus, where it is convenient, we may use representative notional data.

The results of the sensitivity study will be combined with estimates of structural (modeling method) uncertainties in APMT to develop an initial assessment of system level uncertainties. A key element of this activity will be integration with similar analyses that are performed at the module level. For many of the APMT modules, similar parametric studies will be carried out to determine uncertainties in module outputs due to key inputs and assumptions. Uncertainties in the module outputs must be combined with the parametric studies at the system level to perform the overall APMT uncertainty assessment. This analysis can be performed with linked APMT modules, or with surrogate models designed to replicate the individual model behavior. The reason for using surrogates is two-fold. First, it accelerates the rate at which a system level sensitivity/uncertainty analysis can be completed. Second, use of surrogates allows performance of the sensitivity/uncertainty analysis semi-independent of the intricacies of integration of disparate tools and modules. This overall assessment will be used to determine the level of fidelity required at the module level in order to distinguish between different policy scenarios.

MIT will lead the APMT Prototype assessment activity but will necessarily coordinate closely with all other APMT development team members.

13.3 Schedule and Milestones

The schedule and milestones for this part of the prototype development are shown below.

- Work collaboratively with FAA and international stakeholders to define a list of desired uses for capability demonstration (*Provide a list of analysis cases by February 20, 2005)*
- Develop notional scenarios and inputs (*Define inputs and analysis objectives for each capability demonstration case by May 31, 2005*)
- Define policy baseline and policy option scenarios for parametric sensitivity studies (*Develop all inputs and analysis objectives defined for parametric sensitivity studies by May 31, 2005*)
- Carry out parametric sensitivity studies after integrated prototype is available from integration team on August 31, 2006 (*Provide an APMT Prototype Assessment and Recommended Work Plan Report for subsequent review by stakeholders by December 31, 2006)*

14 STAFFING PLAN

Approximate resource and staffing allocations are shown below. (FTE is a full-time equivalent.)

1. Aviation Operations Generator Module
    - WYLE: 0.5 FTE Staff Member (via AEDT)
2. Fleet Selection
    - MVA: 0.15 FTE Staff member
    - GT: 1.0 GRA, 0.1 FTE Research Engineer
3. Manufacturer Costs/Aircraft Prices Module
    - MIT: 1 GRA, 0.5 FTE Research Engineer or Postdoctoral Associate
    - GT: 0.5 GRA, 0.1 FTE Research Engineer
4. Airline Operating Costs Module
    - MVA: 1.0 FTE Staff member
    - MIT: 0.1 FTE Research Engineer
5. Fares Assumptions module
    - MITRE-CAASD: 0.1 FTE Staff member
6. Future Air Transport Demand module
    - MITRE-CAASD: 0.2 FTE Staff member
7. General Economy Block
    - MITRE-CAASD: 0.1 FTE Staff member
8. Benefits Valuation Block
    - MIT: 2 GRA , 0.7 FTE Research Engineer
9. Interface, Analysis and Display
    - GT: 0.5 GRA, 0.18 FTE Research Engineer
    - MVA: 0.03 FTE Staff member
10. APMT Integration
    - GT: 3 GRA, 0.5 FTE
    - MIT: 0.25 Research Engineer or Postdoctoral Associate
    - MVA: 0.25 FTE Staff member
11. APMT Assessment
    - GT: 1 GRA, 0.3 FTE Research Engineer
    - MIT: 1 GRA , 0.5 FTE Research Engineer or Postdoctoral Associate
    - MITRE-CAASD: 0.1 FTE Staff member

- MVA: 0.1 FTE Staff member

12. APMT Communications

    - MIT: 0.1 FTE Communications Professional + travel of development team members to CAEP and other meetings for interfacing with stakeholders, sponsors, and other team members.

15 BEYOND THE PROTOTYPE: DEVELOPING APMT VERSIONS 1-3

The goal in constructing the APMT Prototype is to identify gaps or weaknesses in the APMT architecture and to stimulate advancements in development of APMT. Therefore, as described, we will construct all of the functional modules of APMT—but with more limited capabilities than planned for the final versions. We will test the functionality of APMT for addressing various policy questions, and we will assess and propagate uncertainties from the module level to the APMT system level to guide the determination of high priority areas for future development and refinement.

This section provides preliminary information on the effort to move beyond the APMT Prototype to the development of functional versions of APMT. The APMT Requirements Document defines the recommended time frames for development and use as well as the geographical and economic scope for analyses performed using APMT. In Table 1, an overview of this information as it appeared in the APMT Requirements Document is presented.

To respond to near-term needs, the APMT Requirement Document recommends that the FAA start immediately to develop the capabilities for cost-effectiveness analysis that would encompass but go beyond current ICAO CAEP capabilities. The capability should be operational within 1-3 years, accept a range of environmental performance indicators from AEDT (e.g. number of people living within DNL 65dB, kg NOx, kg fuel burn, etc.) and enable a first assessment of indirect environmental effects that policy options in one domain may produce in another domain (e.g. the effects of noise stringency on NOx levels). It was also recommended that the FAA immediately start to develop the capabilities for benefit-cost analysis within the primary aviation markets, to include monetization of benefits and partial equilibrium modeling of the consumers and producers in the primary market. Pending the availability of data, it is expected that this capability would be developed first for application within the U.S. (within 1-3 years) and then expanded internationally through partnerships and collaborations (4-6 years). The objective is for benefit-cost analysis (the recommended basis for policy analysis in the North America and Europe) to ultimately supplant the near-term reliance on cost-effectiveness analysis.

To address longer-term needs (3-8 years), APMT development should focus on expanding the above capabilities first to include the addition of indirect and induced costs within the broader economy. This should be done through developing a general equilibrium model, which would also allow for a greater range of distributional analyses. Then, as environmental economics research continues to mature, it will be necessary to include indirect and induced benefits to provide a complete capability for environmental economics analyses.

Table 1: APMT Requirements Timeline

Development Time Frame	Title	Scope	Capabilities
Years 1-3	APMT v1 Enhanced Cost-Effectiveness Capability	National/Global	Cost-effectiveness analysis which replicates existing CAEP practice, but uses inputs from AEDT to provide integrated assessment of noise, local air quality and climate variables (CEA.1 and CEA.2)
Years 1-6	APMT v2 Benefit-Cost Assessment Capability	National/Global	Add monetized benefits and partial equilibrium modeling of the primary markets (BCA.1.1 and BCA.2.1) enabling limited distributional assessments (DA.1 and DA.2)
Years 3-8	APMT v3 Benefit-Cost Assessment Capability with Indirect and Induced Costs	National/Global	Indirect and induced cost assessment using a general equilibrium model (BCA.2.2) to enable more complete distributional assessments (DA.1 and DA.2)
Years 6-8+	APMT v4 Benefit-Cost Assessment Capability with Indirect and Induced Costs and Benefits	National/Global	Addition of indirect and induced benefits
Years 6-8+	APMT-Local v1	Local/Regional	Perform benefit-cost assessment on local/regional scale

The first year prototyping effort will serve as an important foundation for moving from the APMT Prototype to APMT Versions 1-3. This will be formalized through the APMT Prototype Assessment and Recommended Work Plan Report (see schedule and milestones for Section 13). This report will synthesize module-level assessments and recommendations, as well as system-level assessments and recommendations, leading to the development of a detailed multi-year APMT development plan. The report will be circulated for review by stakeholders. Although we will use the above timeline and functional requirements for the various versions as a guide, we anticipate that knowledge gained in the first year may influence aspects of subsequent APMT development; for example, we already anticipate being able to offer a capability for representing the general economy, such as through the use of multipliers, with APMT Version 1.