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DECISION SUPPORT FOR ADVANCED AVIATION CONCEPTS

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ABSTRACT

This paper describes The MITRE Corporation Center for Advanced Aviation System Development (CAASD) research towards simulation of advanced aviation concepts. Research activities are aimed toward improving tactical and strategic decision making methods in the near and long term. We describe how CAASD simulation capabilities assist in determining how to achieve our goals for improving tactical and strategic decision making. For the long term, our simulation capabilities are becoming more agent-based.

1 INTRODUCTION

CAASD is involved in simulation modeling and research at the strategic and tactical levels. Tactical modeling addresses air traffic control and traffic flow management. Strategic modeling addresses permanent changes to the national airspace system. Near-term projects focus on decision-making strategies for the next few years. Long-term research focuses on determining how tactical and strategic decisions will be made beyond several years out. Table 1 categorizes some of the current CAASD research toward advanced aviation concepts that use CAASD simulation models.

Table 1: CAASD Near-term and long-term Research toward Advanced Aviation Concepts

	Near-term projects: Decision-making	*Long-term research: Advanced concepts*
Tactical	Traffic Flow Management	Probabilistic Traffic Flow Management
Strategic	Infrastructure changes	Institutional Change

2 NEAR-TERM TACTICAL

Tactical traffic flow management decision support requires a different kind of modeling and simulation capability than that used for strategic applications. While strategic applications often require modeling the general statistical characteristics of traffic flows in order to predict the average or typical impact of system changes, tactical applications require predicting the specific traffic which is currently airborne or planned to be airborne in the next few hours. Also, to provide useful decision support, the capability needs to provide trial planning tools to project the impact of proposed traffic flow management initiatives on the traffic flows.

The FAA/CAASD Collaborative Routing Coordination Tools (CRCT) program is focused on developing such tools (Wanke 2000). The CRCT concept development prototype predicts future positions of all flights in the national airspace system based on their currently-filed flight plans, radar surveillance data, and the current departure delay status of airports. These positions are used to predict traffic levels at key national airspace system resources, namely enroute sectors and airports.

With this base data set, users can identify flow problem areas due to congestion and severe weather. Once a problem has been identified, solutions can be developed and evaluated. For example, in Figure 1, a strategy is being developed to reroute aircraft around a large convective weather system. In this example, two reroutes have been specified, emphasized by two bold series of line segments in the lower half of the figure; one for eastbound flights and one for westbound flights.

With the reroutes specified, the CRCT prototype evaluates the impact of proposed strategies in two ways. First, the safety impact is shown in terms of predicted changes in peak en-route sector aircraft counts. The matrix in Figure 2 contains predicted peak sector counts over 15 minute intervals along the vertical axis for each sector.

Each box along the horizontal axis in Figure 2 represents a sector (top number) and a peak count threshold (bottom number). Counts above the threshold produce yellow or red alerts. Figure 2 shows some sectors had yellow alerts (pale boxes) during certain portions of the analysis period. In this example, sectors for which predicted peak

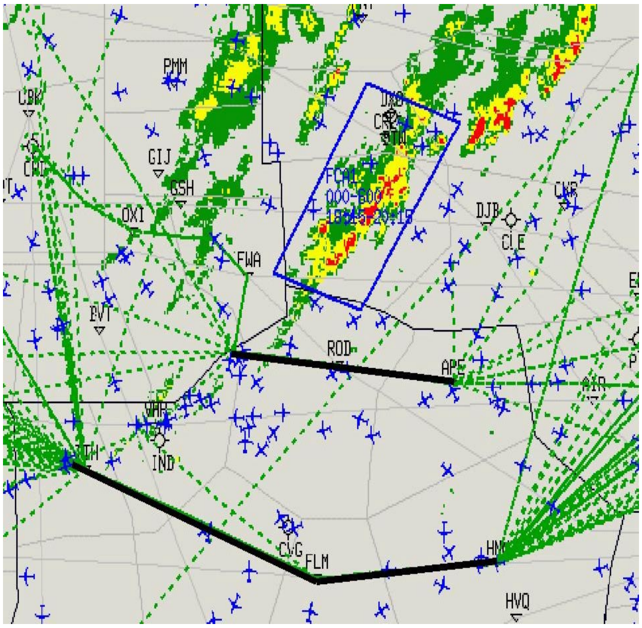

Figure 1: Developing Reroutes around the Weather

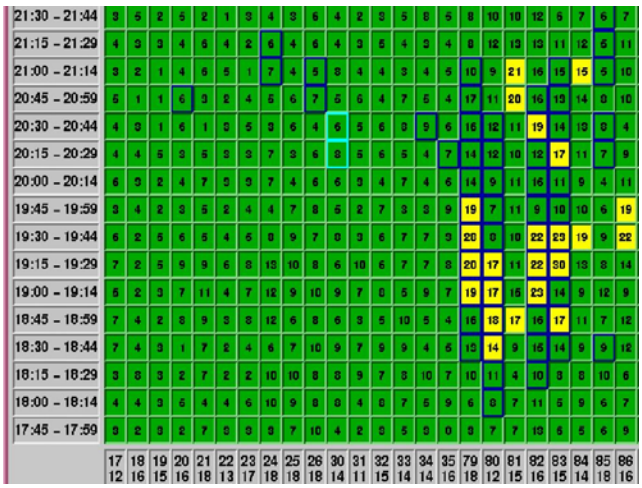

Figure 2: Reroute Strategy Evaluation with CRCT

counts will increase with the reroute in place are surrounded by dark, heavy outlines; sectors with decreased peak counts are outlined in a paler shade. Using this data, the traffic manager can adjust the reroute strategy to distribute flight loads better over the involved sectors.

The second way in which CRCT evaluates proposed strategy impacts is by calculating and displaying the time and distance added to involved flights. This data can be used to choose strategies that have minimum economic impact on airspace users.

In addition to reroute strategies, a similar "what-if" capability has been developed to assess imposition of miles-in-trail restrictions. During miles-in-trail restrictions, aircraft are slowed and maneuvered to cross a sector boundary at some minimum spacing (e.g. "20 miles-in-trail") behind the preceding aircraft. This is done to control sector volume, often in combination with a weather-induced reroute. Thus the prototype allows traffic managers to superimpose multiple reroutes and restrictions and develop comprehensive flow management strategies. Further research is underway in providing automation assistance in developing solutions to such complex flow problems.

CAASD has been working closely with the FAA and the Volpe National Transportation Systems Center, on a strategy and supporting plan for deploying CRCT capabilities as part of the operational traffic flow management system. The first CRCT-derived flow problem recognition tools were deployed two years ago in the Enhanced Traffic Management System, the FAA's operational traffic flow management decision support system for the national airspace system, and the rerouting evaluation capability is scheduled for deployment in the Enhanced Traffic Management System this year.

3 NEAR-TERM STRATEGIC

CAASD is responsible for modeling how different kinds of technologies, infrastructure enhancements, and procedural changes could improve airport capacity, increase sector throughput, and reduce delays. Recently the FAA developed the Operational Evolution Plan to meet the air transportation needs of the United States for the next ten years with a focus on maintaining safety, increasing capacity, and managing delays. Over the next few years, CAASD expects to address the performance of the national airspace system with various combinations of improvements.

We analyze national airspace system performance with an aggregate simulation model called the Detailed Policy Assessment Tool (DPAT). DPAT simulates the air traffic system as a network of queues. DPAT can be used to analyze how congestion and delays result from the limited capacities of airports and air sectors, and to forecast future congestion to inform policy-makers about airport and airspace improvement needs. DPAT also models the propagation of delay throughout a system of airports and sectors. DPAT models the flow of approximately 50,000 flights per day throughout the airports and airspace of the U. S. national airspace system and can simulate flights to analyze delays at airports around the world.

We use the Future Demand Generator, a data preprocessor developed by CAASD, to estimate where future flights will fly and connect sequences of flights into itineraries. Each simulated aircraft flies to the airports listed in its itinerary. Linked itineraries are necessary for simulating delay propagation from departure and arrival queues at airports to other airports. General aviation flights are also included in DPAT analyses since they account for some demand at airports and in the airspace. Weather at airports is modeled by reducing the capacities, or increasing the runway service rates, at the affected airports. Airport capacitiy analysis for 31 of the busiest airports in the United States was performed by The MITRE Corporation (2001). Capacities were derived for both good and bad weather situations. For more details about DPAT inputs and architecture, see Wieland (1999).

The results of a typical national airspace system simulation analysis are in terms of schedule delays and queueing delays. Queueing delays are an indication of capacity problems at an airport. Schedule delays include propagated delays by an aircraft from one airport to subsequent airports in its itinerary. Several combinations of itineraries and capacities are run to represent different demand growths and different national airspace system enhancements, such as adding runways or improved technology to airports. Results from each set of runs are compared to assist in deciding which improvements have the best impact on the national airspace system. Figure 3 shows an example of the reduction of delays at an airport for a ten year period as the airport capacity increases by 10%, 30%, and 80% more than year 2000 capacity, for a particular type of enhancement. The delays are plotted for increasing air travel demand predictions for year 2000 through 2010.

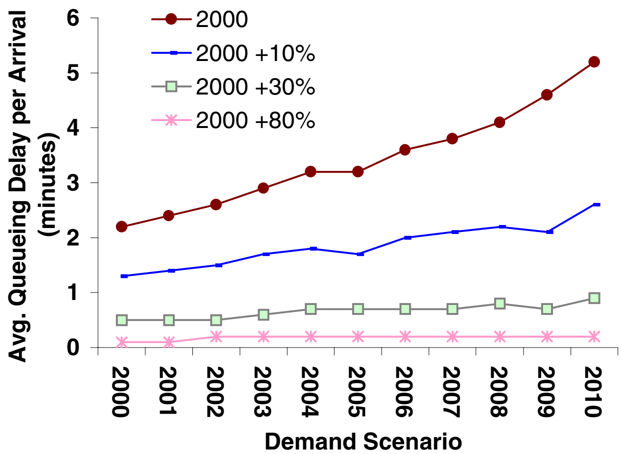

Figure 3: Delays at an Airport for Years 2000 through 2010 with Different Airport Capacity Enhancements

The character of air travel demand is expected to change in upcoming years due to reduced costs of individualized air travel. Predictions (Airbus 2000, Boeing 2001, Holmes 2000, Huettner 2001) state that demand for small aircraft will grow much more than demand for air travel by the traditional hub-spoke system. Figure 4 specifies broad categories of aviation demand, as well as other (non-air) modes of transportation. As transportation gets farther from the hub, it becomes less stable and less predictable. In general, larger growth rates are expected for the less predictable types of demand than for hub service, which today predominates in terms of number of passengers. CAASD is working on developing new strategic modeling capabilities within its aggregate simulation models to address different types of demand.

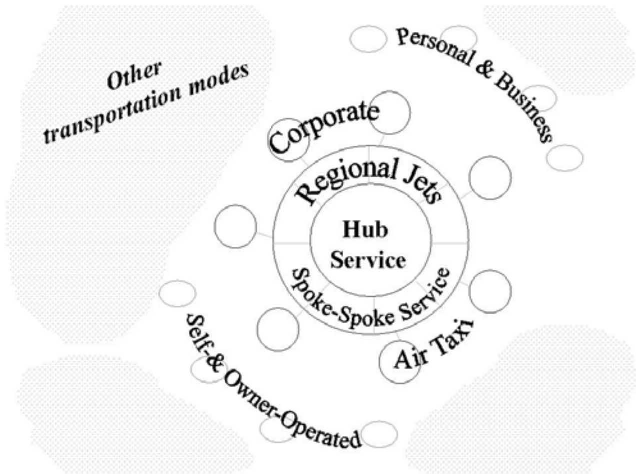

Figure 4: Levels of Long-distance Travel Demand Expected to Change in Upcoming Years

4 LONG-TERM TACTICAL

CAASD strives to improve decision making regarding air traffic flow management, which is the daily process of managing flows of traffic to airports and sectors with limited capacity. Presently, decision-making by the FAA at the Air Traffic Control System Command Center does not fully account for information uncertainty, especially regarding weather impact predictions. Often, decisions are based on what seemed to work or did not work in recent operational experience, rather than on a probabilistic understanding of weather predictions. The FAA has recognized the need for greater attention to incorporating an understanding of uncertainty in its operations, and has termed this area “probabilistic traffic flow management.”

The initial objective for improving tactical modeling is to develop a model to aid traffic flow management post-event analysis with uncertain weather forecasts, based heavily upon actual experience with weather events in the past. The final objective is to change decision-making policies to reflect information uncertainty. If successful, the tool has the potential to fundamentally change decision-making strategy, and to benefit the flying public during aviation schedule disruptions caused by weather.

Decision analysis is a well-understood framework for assessment of decision making with uncertain information. To begin our study of probabilistic traffic flow management, we have applied the decision analysis framework in the context of an agent-based model to show how FAA traffic flow management decisions could be assessed on the basis of the distribution of possible outcomes following an uncertain weather forecast (Wojcik 2001a). The agent-based model, called Intelligent agent-based Model for Policy Assessment of Collaborative Traffic flow management

(IMPACT), represents individual airlines and the FAA as independent, self-interested agents within a simulated traffic flow management event.

IMPACT models arriving flights to an airport whose capacity is limited. Weather effects are represented by reduced capacity for some period of time. Airline and FAA agents make decisions based on specified decision criteria and available information. Airline agents make decisions heuristically based upon anticipated future costs. As in real traffic flow management operations, their decisions include whether or not to cancel, delay or exchange the arrival times of their scheduled flights. Each airline is self-interested, so airlines' goals often conflict, and the effect of this conflict on aviation operations has been modeled with IMPACT as well as other more aggregated models (Campbell et al. 2001 and Wojcik 2001b).

The FAA agent in IMPACT makes decisions about whether and when to exercise system-level actions called ground delay programs and ground stops. Ground delay programs and ground stops are demand management options exercised by the FAA in real traffic flow management operations. A ground delay program controls arrival demand at the affected airport by revising the departure times of flights to reduce the arrival rate to a desired level. Typically a ground delay program is declared hours in advance of an anticipated capacity reduction due to weather. A ground stop controls demand at the affected airport by holding all scheduled arrival flights on the ground for some period of time. A ground stop is a more drastic action than a ground delay program, and it is used when the FAA determines that a serious demand problem warrants such an action.

Sets of IMPACT scenarios were created to illustrate the tradeoffs inherent in decision making with imperfect weather forecasts at an airport. Each scenario set corresponds to a different strategy option to respond to a four-hour forecast of weather at the airport. In strategy option 1, the FAA made a decision about whether to declare a ground delay program, and the characteristics of the ground delay program, at the time of the four-hour forecast. In strategy option 2, the FAA made a ground delay program decision after waiting two hours after the initial forecast. In strategy option 3, the FAA took no actions. For all three strategy options, the airline agents took decisions in response to the FAA's decision and how the weather and other airlines' decisions evolved. Finally, in strategy option 4, neither FAA nor the airlines took any actions to modify the original schedule of arrival flights. Strategy option 4 is not realistic, but was included for comparison against the other, more plausible scenarios.

Figure 5 shows the distribution of cost across 100 IMPACT runs for the four strategy options with perfect weather information. The number of weather scenarios for which average cost per flight fell into each $500 cost bin is shown. Although the variance is large in all cases, on average the lowest cost strategy is when a ground delay program is declared four hours in advance of the event. This is expected, because with perfect information, there is no benefit in waiting for a better forecast, and there is advantage in acting early before flights depart for the affected airport. However, the cost difference between waiting and not waiting was small.

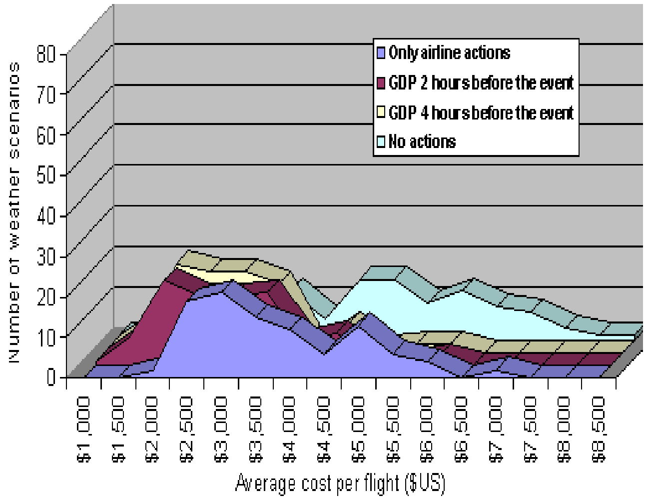

Figure 5: Distribution of Cost with Perfect Weather Information

Figure 6 shows the distribution across the four strategy options with imperfect information. Note that there is a spike in the distribution of cost when a ground delay program is declared 4 hours in advance. This is because the initial forecast is severe, and it turns out that actual weather rarely turns out to be worse than the initial forecast. Thus, a ground delay program based on the initial forecast tends to clamp down demand to a level that is almost always manageable. However, the expected cost for the strategy option of waiting two hours is less. Thus, there is a tradeoff between predictability and expected efficiency.

This simple analysis illustrates how the decision analysis perspective can be applied to understand the effect of decision making strategies over the long term, i.e., many traffic flow management events. However, more work is needed to bring this work into practical use in actual traffic flow management events. The basic limitation of the IMPACT work to date is that it has proven difficult to validate quantitatively against actual events. CAASD is involved in research to attempt to bridge the gap between the theoretical perspective of decision analysis and the complexity of the real world.

5 LONG-TERM STRATEGIC

CAASD is exploring the use of agent-based modeling to analyze the behavior of airlines when faced with changes in the capacity of the national airspace system. The current modeling effort, called Jet:Wise, attempts to define the

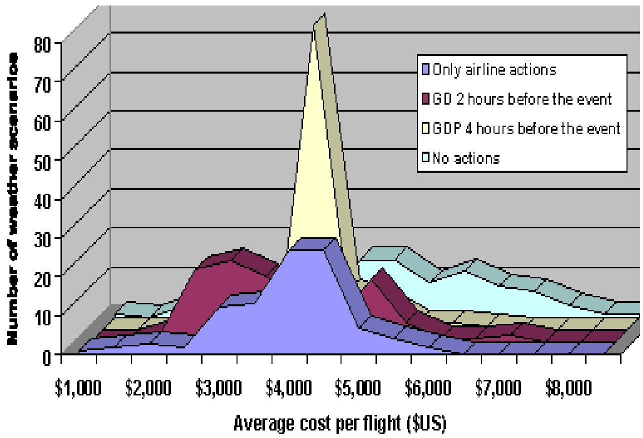

Figure 6: Distribution of Cost with Imperfect Information

characteristics of airlines based on simple rules to deal with increased delay or cost of flight, or reduced passenger demand, for example. Jet:Wise agents address these changes by varying fares, adjusting schedule, changing aircraft size, etc. Agent-based modeling seeks to simulate the interactions of the agents (flights, airline schedulers, etc.) by directing the agents to seek an objective function. In doing so, the model's behavior exhibit emergent behavior, such as increased or decreased airline hubbing. Jet:Wise does this in several phases, as shown in Figure 7.

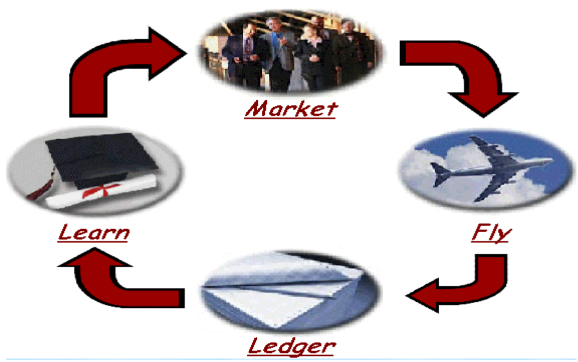

Figure 7: Phases of the JetWise Model

Jet:Wise is suited to researching questions about likely outcomes for broad possibilities such as:

- Airline reaction to a reduction in flight times
- Demographic shifts and their effect on airline service
- How airlines would service demand increases
- New airport stimulatory effect on airline service
- Fleet changes or utilization impact caused by increased or decreased congestion.

Jet:Wise was a spin-off from work on the agent-based IMPACT model, described in Section 4. It is the first attempt by CAASD to apply agent based modeling to the entire air traffic system on a long-term time scale. Much remains to be learned as CAASD continues to explore the application of this exciting technique in the air traffic domain. We expect Jet:Wise to improve our ability to make decisions on infrastructure changes while considering possible changes to aviation business models in the future.

To date, little research has been done to examine the ways in which current and future information technologies will change aviation business models, or the future travelscape. The aviation travelscape can be describes as the sum of products and services that enable travel by air, including lodging, food, and multi-modal transportation. The travelscape is not limited to physical products and services, however. Information technology will play a primary role in enabling the traveler of the future to navigate the travelscape. Figure 8 shows an example of information that could be communicated to a passenger through a personal digital assistant someday, assuming the future travelscape provides a method for this type of information to be transmitted to passengers in real time. The passenger would be able to use the information to select alternate travel options if his flight were canceled. Technological trends in computational speed, wireless connectivity, information exchange and intelligent systems could enable a shift in the industry from supplier-driven to passenger-driven and enable more efficient use of existing assets.

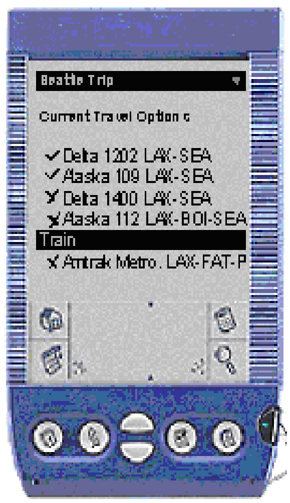

Figure 8: Information Received on a Personal Digital Assistant as a part of a Possible Travelscape Scenario

The objective of the travelscape effort is to create and refine a vision of the future travelscape from a passenger perspective and to relate it to the demand and supply of air traffic services. This project seeks to define the likely areas of demand and examine them for future research consideration.

These demand scenarios can be explored with the Jet:Wise model. For example, to simulate a fleet change scenario where the average aircraft size in airline fleets declines over time, Jet:Wise's aircraft schedules can be adjusted so that they are flown with smaller airplanes than currently exist. Other types of simulation from travelscape findings might include increases in operational costs because of security, avionics requirements, or increased landing fees at selected airports.

6 DISCUSSION

Weather is a major factor in all analyses. There is a need to better understand and model the effects of imperfect weather forecasts on decision-making and system performance. CAASD is working on a tactical modeling of the effect of imperfect weather information in a decision analysis framework. It is an open research question as to how to roll up this understanding to a more aggregated level for strategic analysis

Conventional, non-adaptive modeling is available for our near-term strategic modeling needs, but agent-based modeling will be needed to fulfill many of our long term needs. CAASD is working toward developing better agent-based models to improve our modeling capabilities for future national airspace system analyses. However conventional modeling will still be required in the future; therefore we are still working toward improving our conventional modeling capabilities.

Agent-based simulation can be used to help fill in the gap between infrastructure and institutional changes. Traditional simulation analyses consider only the effects of new technology or new runways on delay. Agent-based models can show the effects of new business models: such as increased fractional ownership of aircraft or aircraft that can be chartered on short notice.

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