REDUCTION OF WEATHER-RELATED TERMINAL AREA DELAYS IN THE FREE-FLIGHT ERA

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ABSTRACT

While much of the emphasis of the free-flight movement has been concentrated on reducing en-route delays, airport capacity is a major bottleneck in the current airspace system, particularly during bad weather. According to the Air Transport Association (ATA) Air Carrier Delay Reports, ground delays (gate-hold, taxi-in, and taxi-out) comprise 75 percent of total delays. It is likely that the projected steady growth in traffic will only exacerbate these losses. Preliminary analyses show that implementation of the terminal area technologies and procedures under development in NASA's Terminal Area Productivity program can potentially save the airlines at least $350M annually in weather-related delays by the year 2005 at Boston Logan and Detroit airports alone. This paper briefly describes the Terminal Area Productivity program, outlines the cost/benefit analyses that are being conducted in support of the program, and presents some preliminary analysis results.

INTRODUCTION

Free flight will revolutionize air traffic in the 21st century. The entire notions of 'delays' and 'system capacity' will change. Theorists, system users, and even system operators speak of potential time and resources savings in the billions of dollars per year. Most free-flight analyses focus almost entirely on the en-route environment, where the operational and economic gains are most evident. However, the potentially huge economic benefits of free flight may remain largely unrealized if the system is bottlenecked at terminals. Despite projected steady increases in air traffic, few new airports or runways are likely for the foreseeable future; thus, for the full benefit of free flight to be realized, airport and runway throughput must somehow be increased.

NASA's Terminal Area Productivity (TAP) research program is developing technologies and procedures to reduce delays in the terminal area of the future. The majority of significant terminal area delays are caused by weather, and thus weather-related delays are the main focus of the TAP program; however, many of the technologies and procedures can also mitigate delays when weather is not a factor. This paper describes the TAP research program and details ongoing system studies that are being conducted to support the TAP program.

THE TERMINAL AREA PRODUCTIVITY PROGRAM

Terminal Area Productivity (TAP) is a NASA research program being conducted in coordination with the FAA to develop technologies and procedures for increasing airport terminal area capacities in non-visual conditions to levels comparable to the capacities realized in clear-weather conditions. TAP is a subelement of NASA's Advanced Subsonic Technologies research program. The TAP research program will be completed in the year 2000, so widespread operational deployment of the TAP technologies and procedures will not occur until perhaps 2005. TAP comprises four subelements: Reduced Spacing Operations, Air Traffic Management, Low Visibility Landing And Surface Operations (LVLASO), and Aircraft/Air Traffic Control Systems Integration.

Reduced Spacing Operations focuses on developing and demonstrating technologies and procedures to mitigate the reduction in arrival capacities of runways currently experienced under Instrument Flight Rules (IFR) operations. This work will result in decreasing the separation requirements between each pair of landing aircraft as well as allowing the independent operation of parallel runways spaced closer than 3400 feet apart. A significant part of this research effort is devoted to theoretical understanding and modeling of the transport and decay of the wake vortices created by aircraft in flight.

The Air Traffic Management subelement is developing and demonstrating a set of automation aids for air traffic controllers in the TRACON. These automation aids will allow fuller utilization of the Flight Management Systems and datalinks that are increasingly available on commercial air transports to increase airport capacity, will support more closely spaced parallel runway operations, and will allow more rapid reconfiguration of operational runways and the terminal airspace.

The LVLASO subelement focuses on mitigating delays in runway occupancy, taxiing, and crossing active runways due to low visibility conditions. This element includes situational display aids in the cockpit, such as taxi-map displays, and controller aids in the tower, such as ASDE-3 (Airport Surface Detection Equipment) enhancements to identify taxiing aircraft on controller displays, as well as technologies and procedures to facilitate pilot/controller communications, such as computer-generated datalink messages.

The fourth TAP subelement, Aircraft/Air Traffic Control Systems Integration, supports integration of the other subelements as well as integrated experiments and simulations to demonstrate concepts. The system studies described in this paper are a major part of this subelement.

TAP SYSTEM STUDIES

The goal of the system studies is to enable knowledgeable, well-founded decision-making for managing the TAP program by determining the most significant weather-related delay problems in the terminal area, determining the usefulness of individual TAP technologies in a systems context, and assessing which solutions are most cost-beneficial. The TAP research program will culminate in the development and demonstration of a number of technologies and procedures to mitigate weather-related delays in the terminal area. The ultimate decision to implement those solutions in the operational environment will depend on whether the FAA and the airlines (and possibly avionics equipment manufacturers as well) are convinced that it is substantially in their financial interest to invest in these technologies.

Approach

Figure 1 illustrates the basic approach being used to conduct cost/benefit analyses of the TAP technologies. The studies are being conducted by a team of civil service NASA and FAA employees plus contractors with Logistics Management Institute (LMI), a Federally-Funded Research and Development Corporation, and with Lockheed-Martin and MCA Research Corporation, under the guidance of the FAA.

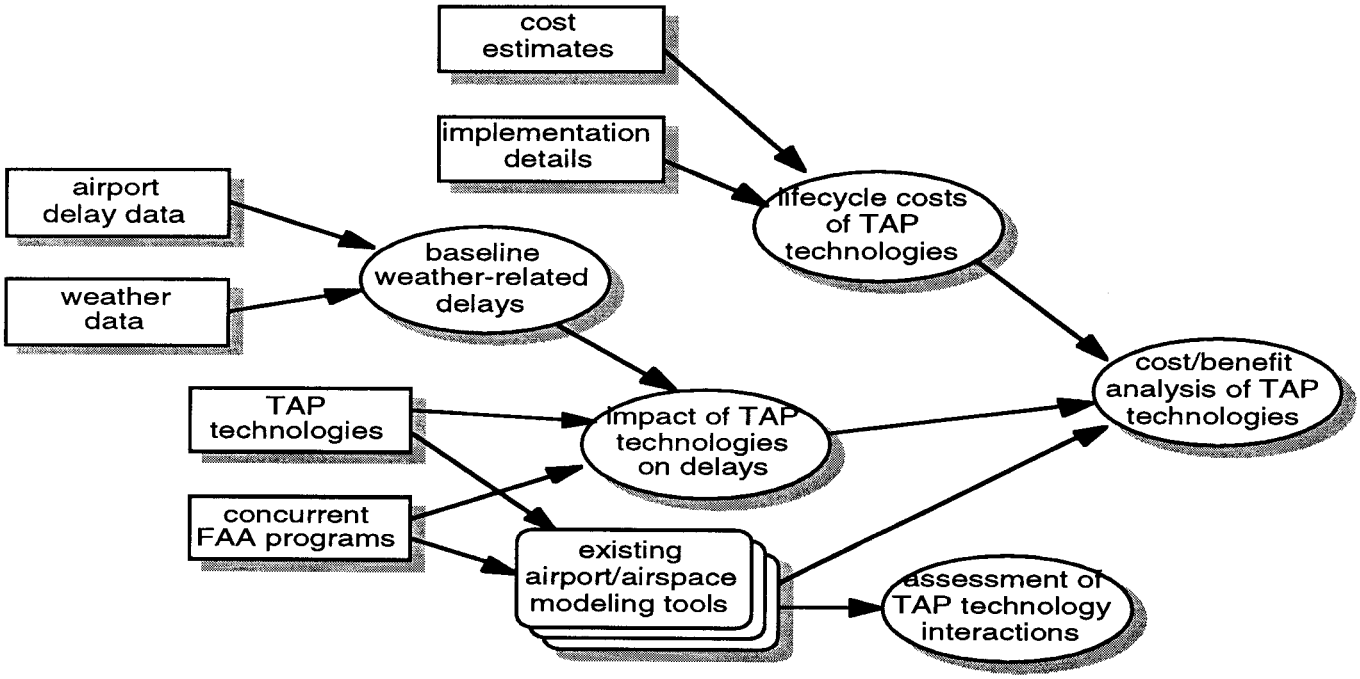

Figure 1. TAP cost/benefit analysis approach

Ten major U.S. airports were chosen for the benefit studies: Boston (BOS), New York LaGuardia (LGA), New York Kennedy (JFK), Newark (EWR), Atlanta Hartsfield (ATL), Chicago O'Hare (ORD), Detroit (DTW), San Francisco (SFO), Los Angeles (LAX), and Dallas-Fort-Worth (DFW). These airports were chosen because they have some of the highest annual delays and rank high in experiencing days with periods of low-visibility weather. The following sections describe the four facets of the TAP system studies:

- Characterization of airport operations and delays
- Survey of surface delays and causes
- Analytical modeling of the approach and landing phases
- Fast-time simulation of surface operations
- Life-cycle cost estimation

Characterization of Airport Operations and Delays Before analysis of the impacts of the TAP technologies and procedures could begin, detailed data on the operations of the 10 airports in various weather conditions had to be obtained.

The first step was examination of existing databases and reports available from the FAA and other government agencies, such as the Official Airline Guide (OAG) and the Consolidated Operations and Delay Analysis System (CODAS). Detailed weather histories of the 10 airports were obtained from the National Climatic Data Center.

Site visits to selected airports were used to understand more fully how airports operate in various weather conditions. Tower counts and detailed descriptions of airport operations and runway configurations used for various weather conditions were obtained from tower personnel.

Since TAP is a long-term research program and the majority of the technologies and procedures resulting from the TAP research will not be operationally deployed until the year 2005 or later, the cost/benefits analyses are being conducted for the years 2005 and 2015, rather than for the present. Therefore, the TAP cost/benefit analyses are being conducted relative to a baseline that already takes into account the delay reductions expected from the operational deployment of technologies and procedures being developed under other FAA and NASA near-term airport/airspace development programs. The FAA Terminal Area Forecast is being used to determine estimated air traffic for those future years.

Survey of Surface Delays and Causes During the data assessment phase of the studies, it was noted that very little data is available on the problems of surface movement in low-visibility conditions. Therefore, a detailed survey is being conducted to collect data on weather-related surface delays [1]. The survey is being completed by airport managers, traffic management specialists, tower controllers plus airline ramp managers and Operations Center personnel. The focus of the survey is on identifying and prioritizing the root causes of surface delays, rather than on collecting hard numeric data, but this information will be important in determining which areas of LVLASO might have the highest payoff. The survey data will also aid in the later development and validation of fast-time simulation models of surface movement at each airport.

Analytical Modeling of the Approach and Landing Phases The effects of reducing the separation between arriving aircraft on a single runway, reducing runway occupancy time, and enabling independent operation of closely spaced parallel runways in low-visibility conditions are being examined through analytical modeling of the approach and landing phases [2]. No existing analytical models were found that allowed the flexibility to accurately model the effects of the TAP technologies, so the following models were developed:

- Runway capacity model - A parametric model of the capacity of a single runway or set of runways operated jointly, that accounts for the effects of meteorological conditions and can be adjusted to reflect the presence or absence of various combinations of the TAP technologies.
- Whole airport capacity model - A model of the capacity of an entire airport as a function of meteorological conditions. This model accounts for the various combinations of runways that can be used in varying wind directions and speeds and in varying visibility and ceiling conditions, with parameters that can be adjusted to reflect the effects of various TAP technologies.
- Demand model - Hour-by-hour airport demand is determined based on tower counts or other data.
- Queuing model - A model that generates delay statistics based on a given time series of capacity and demand.

These four models are used together in the following manner. The parameterized runway and airport capacity models are used to generate a time

series of airport capacity for the weather-days analyzed. A corresponding time series of demand is generated using airport traffic counts or OAG data, adjusted by reference to the Terminal Area Forecast for the desired year. The capacity and demand series are input to a queuing model, which generates statistics on delay. Economic models then estimate the financial impacts of the delays.

Fast-Time Simulation of Surface Operations The effects of the technologies and procedures being developed under the LVLASO subelement to reduce surface delays will be assessed using the Terminal Airspace and Airport Modeller (TAAM) [3]. Fast-time simulations are necessary because 1) surface operations are quite complex and hence difficult to model analytically, and 2) feedback from viewing the simulations can aid in understanding how the various surface technologies and procedures interact.

TAAM is a rule-based 3-D simulation tool with a powerful graphical display that facilitates the systematic and interactive evaluation of changes in operations at an airport. For example, TAAM allows a user to define gates, taxiways, runways, etc. and set usage rules and restrictions to assess improvements to ground operations. TAAM simulations of the three New York area airports, JFK, LGA, and EWR, will be used to evaluate ground delay effects of the TAP technologies that improve poor visibility operations. After modeling the airport layout, actual traffic data will be used to recreate traffic patterns for a bad-weather day. The TAAM model will be calibrated to emulate aircraft performance and taxi, runway, and other airport operations for the baseline scenario. A new scenario will be simulated for each increment of TAP technologies and procedures to be analyzed. For example, to simulate cockpit moving map displays, the new scenario would reflect higher taxi-in/out speeds derived from simulation studies performed in the LVLASO element of TAP. A comparison of the delays incurred from the two scenario simulations will provide a measure of the impact of the TAP technologies and procedures.

Life-Cycle Cost Estimation To complete the cost/benefit analyses, the lifecycle costs of operational deployment, operation, and maintenance of the TAP technologies and procedures will be estimated. Preliminary life-cycle cost estimates will be made early in the research program to aid in programmatic guidance towards the most cost-beneficial research areas. As the research program progresses, these preliminary estimates will be updated to reflect design choices and refined as more data on implementation details becomes available.

PRELIMINARY RESULTS

Some preliminary results from early TAP system studies are presented in this section. These results are from preliminary analytical modeling that has been completed for two of the ten focus airport plus some preliminary results from the surface operations survey forms that have been received to date.

Analytical Modeling

Preliminary results from analytical modeling have shown substantial benefits from implementation of TAP technologies applicable to the approach and landing phases at two airports analyzed thus far, Boston Logan and Detroit, as shown in Table 1. These results must be considered preliminary because they are subject to several limitations, as outlined below. However, they are useful for establishing the rough order-of-magnitude benefits expected from the TAP program.

Year 2005	BOSTON LOGAN		DETROIT	
	Lower Bound Savings $M	Upper Bound Savings $M	Lower Bound Savings $M	Upper Bound Savings $M
TAP 1	$45.30	$81.10	$17.80	$31.70
TAP 2	$156.00	$279.60	$12.10	$21.60
TAP 3	$96.70	$173.40	$26.30	$46.80
FULL TAP	$298.00	$534.10	$56.20	$100.10

Table 1. Preliminary analysis of impacts of TAP technologies on annual delay costs, where TAP 1 is reduced interarrival spacing, TAP 2 is reduced interarrival spacing plus reduced runway occupancy time, and TAP 3 is reduced interarrival spacing, reduced runway occupancy time, plus air traffic control/flight management system interaction to enable more accurate interarrival spacing.

Four separate combinations of TAP technologies were modeled:

- TAP 1 is reduced interarrival spacing, enabled by controller aids for minimum spacing between specific pairs of aircraft including consideration of wake vortex hazards.
- TAP 2 is reduced interarrival spacing plus a 20% reduction in runway occupancy time, and
- TAP 3 is reduced interarrival spacing, reduced runway occupancy time, plus further reduction in interarrival spacing enabled by using onboard flight management systems to accurately deliver the aircraft over the threshold at the time requested by the controller.

These preliminary results illustrate that the impacts of the TAP technologies and procedures will vary significantly from airport to airport. In this case, Boston cannot use key runways in Instrument Flight Rule conditions because of close spacing of parallel runways, hence Boston derives more operational benefit from the TAP delay reductions than does Detroit.

The major limitations to these preliminary analytical results are as follows:

- Only a subset of the TAP technologies and procedures are considered
- Accurate modeling of the expected performance of the TAP technologies and procedures is difficult this early in a research program
- Available data on runway occupancy times is limited and the operating conditions are seldom known. Thus, although this study showed that reduced interarrival separation would make runway occupancy time a significant capacity factor, less conservative assumptions of baseline runway occupancy times show a different result.
- Because only the approach and landing phases were analyzed, assessment of broader system interactions was not included.

The analytical models produce an estimate of the minutes of delay per year for each combination of TAP technologies and procedures. The minutes of delay must then be translated into a cost savings for the airspace users. Since the various airlines and other entities use several different methods for calculating the costs of delays, and the mix of ground and airborne delay is unknown, an upper and lower bound was calculated for this study. The costs per minute of delay used for Boston and Detroit are shown in Table 2.

The upper and lower cost estimates are based direct operating costs, which include fuel, oil, flight crew salaries, benefits, payroll taxes, and insurance. To approximate the cost of ground delays, the lower-bound estimates add cabin crew costs to direct operating costs and then subtract fuel and ownership costs, such as depreciation and amortization. The upper-bound estimates add cabin crew costs to direct operating costs. The upper bound is not a true upper bound on the costs to the airline, since this does not include passenger delay costs, costs for rerouting passengers who missed connections or putting them in a hotel overnight, costs for airline recovery of aircraft and crew relocations, or any estimate of the overall impact of delays to the country's economy. These costs were calculated based on the mix of aircraft operating at these airports (i.e., turboprops, short-haul jets, and long-haul jets); hence the difference in operating costs between the two airports. In fact, both of these airports are significantly below the lower and upper bounds for the average major US airport, which are $24.00 and $43.26, respectively.

Airport	Lower Bound	Upper Bound
Boston	$16.21	$29.06
Detroit	$19.01	$33.82

Table 2. Cost per minute of arrival delays.

Survey on Surface Delays

When airports experience significant weather events, such as rain, snow, ice, or low-visibility, the interarrival separations maintained by the controllers under Instrument Flight Rules (IFR) are somewhat higher than those typically maintained by pilots under Visual Flight Rules (VFR). Parallel runways spaced closer than 4300 ft apart cannot be operated independently, significantly decreasing capacity. Some intersecting runways may be shut down. Other factors, such as wind directions, may require use of less efficient runway configurations, which reduce arrival capacities even further. Furthermore, there are fewer aircraft operating, since most general aviation and many air taxi/commuter aircraft are not properly equipped for IFR conditions. It is expected that ten years from now the percentage of general aviation and air taxi/commuter aircraft equipped for IFR operations will increase. Therefore, the surface delays identified in the survey of operations today can only expect to be exacerbated by not only normal traffic increases but also by the increased numbers of IFR surface operations expected in 2005. However, the technologies and procedures being developed under TAP as well as other ongoing programs promise to significantly improve the situation over the next ten years. The TAP program aims to enable reduced IFR interarrival separations, independent operation of parallel runways spaced closer than 4300 ft apart.

The survey to collect data on surface movement delays and their causes is still ongoing, and fewer than half of

the airport responses have been received to date. However, some trends are evident from these preliminary results.

Runway Occupancy Time (ROT) does not appear to be a factor in surface delays under the current environment and procedures. Wake vortex separations are large enough today that the typical ROTs at major airports (approx. 50 sec or less) do not slow arrivals. When separations are reduced or multiple glide slopes approaches are implemented, ROT would become a limiting factor. There are a number of factors that influence ROT--in addition to the obvious factors such as aircraft weight, wind direction and runway conditions, there are less obvious factors such as pilot motivation, airline policy, gate location, and pilot technique. In fact, there is some evidence that pilots operating in IFR conditions have increased awareness of the need for exiting the runway quickly, resulting in lower ROTs than in VFR. Analysis of the currently available ROT data is difficult because of the many factors affecting ROT; thus, this is an area requiring future study.

Once the aircraft exits the runway, taxi speeds are not significantly affected by weather unless the pilot's short-range visibility is impaired or when surfaces are slippery. However, crossing other active runways is frequently slower under IFR because more controller communication and guidance are needed to make up for low-visibility. Controller displays such as ASDE-3 are a help, but the controllers report that the pilots also need situational awareness displays in the cockpit for safe and efficient active runway crossings in low-visibility conditions.

The vast majority of surface delays are incurred waiting in the departure queue, and the second highest surface delays at many airports are spent waiting for gates to become available. These queuing delays result from lack of capacity, airline scheduling, air traffic control inefficiencies, en route or destination weather, or airspace congestion. In the New York City area, airspace congestion and restrictions intensify the severity of ground delays. Since there is virtually no flexibility to divert, arrivals are heavily favored over departures when there is airspace congestion, and this increases departure delays and surface congestion.

Completion of Preliminary Analyses

Only a subset of the TAP technologies and procedures have been analyzed to date. A preliminary cost/benefit analysis of all of the TAP technologies and procedures will be completed by December 1997. This will include a rough estimate of life-cycle costs, analysis of parts of TAP not yet modeled, including independent operation of closely spaced parallel runways, and analysis of additional increments and combinations of TAP technologies and procedures.

CONCLUDING REMARKS

As described in this paper, preliminary analyses have shown that implementation of the terminal area technologies and procedures under development in NASA's Terminal Area Productivity program can potentially save the airlines at least $350M annually in weather-related delays by the year 2005 at Boston Logan and Detroit airports alone. Advanced technologies and procedures to support free flight, whether en route or in the terminal area, will have to be integrated effectively. The TAP program is addressing potential bottlenecks that could greatly reduce the impact of any free-flight strategy. According to the Air Transport Association (ATA) Air Carrier Delay Reports [4], ground delays (gate-hold, taxi-in, and taxi-out) comprise 75 percent of total delays. It is likely that the projected steady growth in traffic will only exacerbate these losses. Unless terminal area delays can be mitigated, airlines will not be able to take full advantage of the en-route travel time reductions possible with free flight because schedules will still have to be padded to allow for terminal area delays.

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