FAA/EUROCONTROL Cooperative R&D
Action Plan 5 and Action Plan 9

Traffic Flow Management (TFM) in Fast-time Simulation: Current and Future Capabilities

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Executive Summary

Under the auspices of the Action Plan 9 (AP9), "Air Traffic Modeling of Operational Concepts", the Federal Aviation Administration (FAA) and EUROCONTROL sponsored a research project to determine the current state of Traffic Flow Management (TFM) simulation in fast-time modeling. The main objectives of the 2005 AP9 TIM were developed to set a foundation for future research efforts. Objectives included the identification of the major differences in TFM practices between the U.S. and Europe; identification of existing fast-time TFM modeling capabilities, tools and modeling techniques; determination of any gaps between fast-time modeling capabilities to address current and future TFM operations and concepts, and the sponsoring organizations needs and requirements.

A research plan was created to identify activities that would support achieving these objectives. Through a multi-step process, the plan called for identification of: (1) current and proposed TFM functions and initiatives as implemented in U.S. and Europe, (2) TFM modeling capabilities that are presently covered by fast time simulation models, and (3) requirements for modeling future TFM concepts.

Exchanging the necessary information between practitioners from the U.S. and Europe was recognized as the most efficient way to initiate this research effort. Toward this end, a Technical Interchange Meeting (TIM) was organized and held in Atlantic City, New Jersey, USA on November 7-8, 2005, hereafter referred to as the 2005 AP9 TIM. The 2005 AP9 TIM provided a forum for subject matter experts to present and discuss a number of topics including; the TFM practices used in the U.S. and Europe, the capabilities of their TFM modeling tools, the identification of other tools that could be used for fast time TFM modeling, and to specifically discuss important issues in TFM modeling, such as plans for future model development efforts. Using the information exchanged during the 2005 AP9 TIM a survey was designed and distributed to gain a better understanding of the capabilities of existing fast-time TFM modeling tools. The survey participants were asked to provide comprehensive information about the tools being investigated, including their general characteristics. This information included hard-coded and user-specified input parameters; logic implemented to mimic TFM initiatives, planning horizons and operations; recorded outputs and metrics, and the animation/display capabilities.

Responses were received from 15 organizations and 22 subject matter experts. These responses provided detailed information on 24 TFM fast-time modeling tools. The survey information was augmented by information collected from various relevant FAA and EUROCONTROL documents and other publications. Together they provided not only a better understanding of the current state of TFM fast-time modeling relative to the current and future TFM functions and initiatives that already can be adequately modeled, but also the TFM elements of fast-time models that require either improvement or development.

The results of the survey show that capabilities to realistically model TFM operations and the corresponding impacts exist in current tools; although differences in objectives, logic and modeling approach limit the fidelity of the observed tools. It is also important to point out that even though many of the necessary capabilities are already developed, they do not live

within a single tool; this observation, as well as all other observations offered within this report, is limited to the 24 surveyed tools.

Based on participant discussion at the TIM and the survey responses, Collaborative Decision Making (CDM) and automated CDM were identified as key concepts continuing to enable TFM operations in the future, and, consequently, as a capability that should be integrated into TFM tools to provide for more accurate modeling of current and future TFM concepts. In addition, dynamic re-sectorization, multi-sector planner and 4D trajectories were identified as new TFM concepts that will need to be assessed in the near future; these are likely to be followed by a need to investigate open-loop TFM-4D, implementation of Network Operations Plan (NOP) and interactions between elements of future concepts.

In addition to the future TFM concepts listed above, additional areas in need of research and development were identified as follows: (1) capacity as a function of traffic complexity and environmental factors such as characteristics of weather, and (2) connectivity between the human performance and the system performance. Responses also revealed that the fidelity and capabilities of some models could be significantly improved by linking them to other models; however, this is not always easy or even possible due to different operating systems or other technical requirements associated with the tools. Most of the practitioners' agree that a more open, modular, flexible architecture, such as Hight Level Architecture (HLA), component-based and agent-based architectures are needed to evaluate TFM and future TFM concepts. Future AP9 activities coming from this TIM (such as surveys and papers) will address all these issues.

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1 Background

The Federal Aviation Administration (FAA)/EUROCONTROL Research & Development (R&D) Committee was established in December 1995 during the second FAA/EUROCONTROL R&D Symposium, held in Denver, Colorado. The focus of the FAA/EUROCONTROL R&D Committee was to define priorities in terms of common actions and agendas of both organizations. The Committee identified areas of mutual interest where the FAA and EUROCONTROL could work together in R&D and defined several R&D Cooperative Tasks, which are referred to as 'Action Plans'.

Action Plan 5 (AP5), entitled "Validation and Verification Strategy" is one of those actions plans. Its objective is to determine a strategy for validating and verifying the performance, reliability, and safety of Air Traffic Management (ATM) systems and its possible relations to certification. This strategy is captured in the Operational Concept Validation Strategy Document (OCVSD) [1]. Fast-time simulation plays a key role in operational concept validation and is essential in meeting the objective of AP5.

Action Plan 9 (AP9), entitled "Air Traffic Modeling of Operational Concepts" was developed to meet a different set of objectives. These objectives are:

1) To promote mutual understanding between the United States (U.S.) and Europe on the use and development of Fast-Time Simulation models for modeling of Air Traffic operational concepts.
2) To identify areas for practical co-operation in the use and development of Fast-Time Simulation models.
3) To build upon on-going efforts in the U.S. and Europe to develop modeling capabilities.
4) To support inter-connectivity of models and the use of standard input data for models where appropriate.
5) To promote best practice and lessons learned in the use of Fast Time Simulation models by U.S. and European partners.

Given the need for cooperation between these 2 Action Plans, AP5 and AP9, a research plan was created to identify activities that would support their intersecting objectives. This plan included the identification of Traffic Flow Management (TFM) areas/functions presently covered by analytical or simulation models and gaps in those TFM areas. Additionally, in order to identify the current TFM functions and needs, a Technical Interchange Meeting (TIM) was created to exchange information between practitioners from the U.S. and Europe. From this TIM a web-based survey was developed to identify the current TFM fast-time modeling capabilities and any gaps found in these capabilities relative to future modeling needs (e.g., future concepts and their integration).

2 2005 AP9 TIM

The 2005 AP9 TIM, titled "Traffic Flow Management (TFM) in Fast-Time Simulation," provided a forum for subject matter experts to present and discuss a number of topics including; the TFM practices used in the U.S. and Europe, the capabilities of their TFM modeling tools, the identification of other tools that could be used for fast time TFM modeling, and to specifically discuss important issues in TFM modeling, such as plans for future model development efforts. The main objectives of the 2005 AP9 TIM were developed to set a foundation for future research efforts. These objectives included the identification of the major differences in TFM practices between the U.S. and Europe; identification of existing fast-time TFM modeling capabilities, tools and modeling techniques; determination of any gaps between fast-time modeling capabilities to address current and future TFM operations and concepts, and the sponsoring organizations needs and requirements.

More than 20 representatives from FAA, EUROCONTROL, Centre d'Études de la Navigation Aérienne (CENA), Deutsche Flugsicherung GmbH (DFS), National Aerospace Laboratory (NLR), National Aeronautics and Space Administration (NASA), and numerous other organizations involved in R&D in ATM, participated in presentations and discussions on modeling TFM in fast-time simulations. A short survey was also administered to identify some of the current and future TFM modeling capabilities. The TIM provided an excellent means to communicate with TFM experts and TFM fast time simulation developers and users, hereafter collectively referred to as practitioners'. The emphasis was placed on TFM practices in the U.S. and Europe, several important modeling issues and the current state of the TFM modeling capabilities, and the needs and requirements for future development efforts. This included identifying future TFM concepts that might be considered for fast time simulation and evaluating whether existing models can be extended to address these concepts.

The TIM also provided insight into the additional needs of the developers and analysts that are neither in the existing literature, nor in previous surveys of fast time ATM modeling tools. These additional needs centered around analysis concerns such as validation methods, data integrity, development standards, and knowledge sharing.

2.1 Presentations and Discussions

The TIM was designed so that practitioners' could present information on TFM and/or TFM modeling. Each presentation was approximately 30 minutes long with 15 minutes added for questions and discussions. A brief summary of each presentation follows:

Presenter: Nigel Makins (EUROCONTROL)
Topic: US - Europe TFM Comparison

This presentation concentrated on the EUROCONTROL report entitled "Comparison of Controller Working Methods and Flow Control Tactics in the USA and in Europe". The focus of the comparison was on controller working methods in the Cleveland and New York Air Route Traffic Control Center (ARTCC) as compared with controllers working airspace in the European core area. The conclusion noted that certain tactical TFM (re-routing, flight level capping, and Miles-In-Trail (MIT)) could be introduced in Europe.

Presenter: Ahmad Usmani (FAA)
Topic: Upcoming TFM Enhancements: The Role of Simulation

A description of the U.S. TFM system, issues the system faces, and potential solutions were presented. Most of the issues dealt with the current software infrastructure. To address these problems, two enhancements are in development: TFM Modernization (TFM-M) and Collaborative Air Traffic Management Technologies (CATMT). During the investment analysis process, these enhancements were simulated using PACER and Jupiter.

Presenter: Nigel Makins
Topic: Delay saving by future concepts related to Air Traffic Flow Management (ATFM)

Mr. Makins presented his views and identified several issues associated with using simulation to assess new concepts in Europe. The main issues encountered were:

- many concepts and many airspaces (Europe)
- how to address key performance areas (ex. Capacity)
- how to support case building (capacity and delay to support a business case)
- how to combine several tools and techniques to achieve meaningful results.

Mr. Makins suggested the possible solution of obtaining expert assessment of potential capacity gains at local levels (ACC, TMA, and airport) based on knowledge gained in real-time simulation and extrapolating to other Area Control Centers (ACC), Terminal Control Area (TMA) and airports using a method of categorizing like airspaces.

Presenter: Yann le Fablec
Topic: COSAAC/SHAMAN – A tool to assess Airspace Management (ASM) & ATFM measures and concepts

COSAAC is a tool that can be used to evaluate the effect of ATFM and ASM measures or concepts. The tool was described as a TFM simulator that can be integrated into fast-time modeling and simulation capabilities. The tool has a slot allocation module that modifies the schedule so that sector capacity is not exceeded.

Presenter: Victor Bustos
Topic: MENTOR

MENTOR is a macroscopic simulation tool that is aimed at supporting the decision making process in Air Traffic Flow and Capacity Management (ATFCM). MENTOR is used to find capacity bottlenecks, forecast ATFM delays, assess tactical proposals (re-routing, level capping, etc.), assess strategic proposals (airspace design) and strategic sector configuration planning. WITNESS is the simulation engine that provides the demand, capacity, and sectoring piece to the MENTOR system.

Presenter: Paul Kennedy
Topic: TAAM

TAAM is a tool used to evaluate the current and future ATM environment. Three objectives were presented; keep refining the model, improve user workflow, and support future concepts through interoperability.

Presenter: Ian Crook
Topic: Modeling the Future National Airspace System (NAS) using multiple modeling agents

A description of a modeling framework was presented. This modeling framework allows for the ability to expand on existing modeling capabilities using a networked modeling infrastructure. The infrastructure provided a proof of concept for a System Wide Information Management (SWIM) infrastructure, a flight object concept, common and shared information, support for collaborative decision-making, and the ability to evaluate cooperative ATM concepts.

Presenter: Robert Windhorst
Topic: ACES TFM Approach

The Airspace Concept Evaluation System (ACES) is a suite of models (software agents) and an infrastructure that runs the models. Its primary purpose is concept evaluation. The system can model en-route, airport/ Terminal Radar Approach Control Facility (TRACON), airport runways, TFM, conflict detection and resolution, Airline Operations Center (AOC), and wind information.

Presenter: Pete Kuzminski
Topic: Mid-Level Model

The Mid-Level Model is a NAS system-wide model used for cost/benefit, alternatives, and design analysis. The model simulates ground stops, ground delay programs, and mile/minutes-in-trial TFM initiatives. Possible TFM enhancements include improvements to current features, endogenous route selection, and strategic traffic management. They also indicated that they are moving to delay-based TRACON constraints as opposed to capacity-based constraints.

Presenter: Gerry McAulley
Topic: Future Concepts Fast-Time Simulation at EUROCONTROL

This presentation provided insight into what EUROCONTROL models and how fast-time simulation could be better used. Also discussed were ideas on how and why we can model future concepts (including TFM initiatives).

Presenter: Manuel Dorado
Topic: Multi-Sector Planner (MSP), Dynamic Resectorization, and Pseudo-TFM Simulation

This presentation addressed the simulation of two future TFM concepts; multi-sector planner and dynamic re-sectorization. Also presented were a Pseudo-TFM simulation, and information on PITOT and its link to fast-time modeling and TFM simulation.

2.2 Conclusions

The 2005 AP9 TIM provided a necessary starting point in capturing the TFM capabilities found in current simulation models and gaps to address future TFM capabilities and requirements. The presentations and discussions revealed that several initiatives and development efforts are being carried out in order to model and simulate TFM; these included addressing TFM performance metrics in the TFM analysis process and the validation of future TFM concepts through fast-time simulation.

It is not surprising that future TFM concepts were the focal point of most presentations and discussions, as they are expected to not only change our current way of thinking about TFM, but also our understanding of future ATM operations and the integration between TFM and ATM environments. Some of these operational concepts are now under development and several validation activities are being carried out in the U.S. and Europe. There was a strong interest in assessing the current capabilities available to simulate and analyze revolutionary concepts such as dynamic resectorization, multi-sector planner, 4D trajectories, open-loop TFM-4D, implementation of Network Operations Plan (NOP), and interactions between multiple elements of future concepts. In addition to the presentations and discussions, a short survey was distributed to the participants. This survey captured some of the current TFM capabilities and identified some of the future requirements. The extended survey (see section 4) was planned to gather additional information on current capabilities and areas where further or new development activities were required. The results of the short survey conducted at the TIM follow:

- Collaborative Decision Making (CDM) and automated CDM were discussed as key concepts continuing to enable future TFM operations and, consequently, as capabilities that should be integrated into future TFM simulation tool suite. The primary goal in modeling CDM is to provide the ability to model the TFM interaction with the AOC, and the ability to model airline decision making (e.g., flight cancellations (found in few models) and flight swapping/substitutions). A few of the models surveyed also displayed the capability to model CDM between multiple ATM actors, including the negotiation of flow problems and capacities and the delegation of separation to the cockpit. An additional component to CDM is the aviation systems information network. Only one of the surveyed models was identified as capable of modeling the information exchange between ATM actors and the System Wide Information Management (SWIM) network. Additional future modeling requirements identified at the 2005 AP9 TIM included the ability to model the coordinated actions of pilots, service providers, airline dispatch centers (e.g., managing flow problems), the Network Operation Plan, and new TFM actors and their roles.

- Dynamic Airspace and/or Dynamic Resectorization were recognized as emerging concepts that require thorough investigation; therefore, a capability to model and investigate these concepts was also identified as a future requirement, as well as additional research to meet the needs of the users.

- MSP was also recognized as an emerging concept that requires thorough investigation. Only a few models have begun to explore capabilities and requirements for modeling MSP. It was recognized that as the concept matures, as with all concept oriented models, the modeling requirements will change. Recognizing this early and providing flexibility in the model to accommodate these changes will increase efficiency in future model development efforts. One model was noted that had the ability to simulate MSP as defined by the Gate to Gate project in Europe.

- Flight Diversions occur for many reasons, such as weather avoidance, Special Use Airspace (SUA) avoidance, controller preference, pilot/airline preference, etc. These diversions are an integral part of daily operations, especially with regard to weather avoidance. The response to the survey indicated only a few of the models had the capability to divert flights. One response indicated that all diversions were calculated before takeoff and not during flight.

- Alerting Algorithms, such as Dynamic Density and Monitor Alert, can be used in fast-time simulation as a workload or capacity indicator. Only two responses indicated that their models used some type of load monitor.

- Traffic Metering is the act of spacing aircraft so that demand on a resource (i.e. sector, fix, airport, etc.) does not exceed its capacity. Traffic Metering is considered in many of the surveyed models through near-term tactical initiatives such as miles-in-trail, minutes-in-trail, or in merging flows. However, none of the responses indicated a long-term strategic answer to Traffic Metering.

- A new area of research that was identified as a future requirement for fast-time simulation is 4D trajectory management and 4D contracts. 4D trajectory management is the ability to manage an aircraft trajectory through each phase of flight ensuring that demand on resources (i.e. sectors, airports, fixes) is not exceeded. A 4D contract is an agreement to follow a given 4D trajectory to ensure conformance.

TFM is a global mechanism to ensure fluid allocation of air traffic demand into the system. This requires simulation of TFM through fast-time modeling to perform system wide analysis and assessment of global network effects and impacts. From the perspective of validating concepts, the idea was presented that it would be useful to have tools assist in the “investment analysis” of future concepts. This notion would extend the scope of validation from “validate the concept” to “validate the investment needed to research and develop the concept”. This extension will require the support of new analysis tools and capabilities that address system wide issues and global networks more broadly.

TFM continues to evolve and new concepts, such as 4D management, and new analytical capabilities such as “investment analysis”, need to be addressed by our models. However, current models suffer from limitations in software design (i.e. closed block, structured) that makes it difficult to evaluate new concepts and add new analytical capabilities. Some models are even becoming obsolete. Most of the practitioners' agree that a more open, modular, flexible architecture, such as High Level Architecture (HLA), component-based and agent-based architectures are needed to evaluate TFM and future TFM concepts. Future AP9 activities coming from this TIM (such as surveys and papers) will address all these issues.

3 TFM Terms and Definitions– US and Europe

Augmenting the information provided by the subject matter experts at the 2005 AP9 TIM with a comprehensive literature survey of documents elaborating on the TFM practices, functions, and initiatives implemented in the U.S. and Europe, led to the development of the following sections.

3.1 TFM Practices in the U.S.

The following section represents a summary of descriptions of TFM programs, functions, systems, offices and standard operating procedures as described in [2] - [6].

In the U.S., TFM is centrally run from the David J. Hurley Air Traffic Control System Command Center (ATCSCC). The ATCSCC coordinates with Traffic Management Units in all 20 Air Route Traffic Control Centers (ARTCC) and major metropolitan TRACON's. Together they evaluate and provide planning and management to ensure safe and efficient flow of traffic across the NAS. In cooperation with air carriers and airports, Traffic Management Supervisors (TMS) and Traffic Management Coordinators (TMC) use CDM to manage the flow of traffic. Through automation and procedures, they consider safety and security concerns, weather development, equipment outages, special use airspace, flight restrictions, airport delays, etc., to adopt the most appropriate TFM program that will reduce flight delays by optimizing aircraft routing and traffic flows.

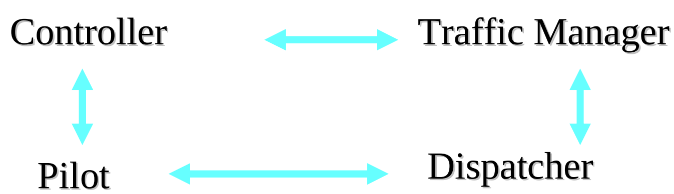

Figure 1. Illustration of a Nominal TFM Communication Process.

In addition to the above mentioned TFM personnel, air traffic controllers from all ARTCC's and selected terminal facilities also participate in TFM activities. In short, Traffic Management personnel analyze the demand on the system and implement initiatives that are then relayed to the controllers. Information flow is two-way. Air traffic controllers and system users also relay information to traffic management personnel for use in decision-making. Traffic Management is the craft of managing the flow of air traffic in the NAS based on capacity and demand. Traffic management personnel analyze data several hours in advance of decision making to determine a plan for managing demand with capacity in a manner that is likely to provide air traffic controllers with a manageable situation. As time passes, the plan is dynamically adjusted in response to current and forecasted conditions. The TFM planning horizon is typically six hours or less and as needed for other Traffic Management Initiatives (TMI). However, data is available to support analysis up to 15 hours in advance of decision-making.

3.1.1 TFM Programs, Function, Systems and Offices

<u>**Collaborative Decision Making**</u>

The CDM Program aims to develop and implement new technologies and procedures to enhance the efficiency of traffic flows across NAS through collaboration between the industry and government [6]. Major stakeholders include the Airlines, Air Transport Association (ATA), National Business Aviation Association (NBAA), Regional Airline Association (RAA), and the FAA.

Part of the CDM Program is a national telecom, held every 2 hours, consisting of Traffic Management personnel, air carriers, and others that develop or update plans based on the current traffic flow and weather. Traffic management personnel utilize numerous weather products to help formulate their plan for the day. Terminal Area Forecasts (TAF) are developed to describe anticipated weather conditions at airports. In the U.S., these forecasts are produced every eight (8) hours by the National Weather Service (NWS). Convective outlooks forecast the most severe thunderstorms in the U.S. for the next 18 hours. They are updated several times throughout the day. The Collaborative Convective Forecast Product (CCFP) is a forecast for intense convection activity that is made for 2, 4 and 6-hour periods by a group consisting of the NWS, the airlines, ARTCC weather units, the Canadian meteorologists service, and the weather unit at the ATCSCC. The CCFP is discussed, critiqued, and adjusted to develop a forecast based on many different inputs. It is the primary planning weather tool for traffic management personnel during severe weather periods. The decision on where to implement Ground Delay Programs (GDP) can be discussed during these telecoms.

GDP is a traffic management procedure when aircraft are held on the ground in order to manage demand with capacity at a specific location by assigning arrival “slots” to aircraft. GDP are normally implemented at airports where capacity is reduced due to, for example, low ceilings, or when demand exceeds capacity for sustained period.

Ground Stop (GS) is a procedure requiring aircraft that meet specific criteria to remain on the ground. The GS may be airport specific, or related to a geographical area or to equipment problems. GS are used when air traffic control is unable to safely accommodate additional aircraft into the system. They are most frequently used for severely reduced capacity situations such as:

- weather below user arrival minima,
- severe weather reducing usable routes,
- major equipment outages,
- catastrophic events,
- precluding extended periods of airborne holding,
- precluding sectors from reaching saturation levels, and
- precluding airports from reaching gridlock.

GS are normally based on distance (flying time). Most GS are reactive to the current situation; however, in some situations, they may be planned in advance.

Enhanced Traffic Management System

The Enhanced Traffic Management System (ETMS) is an operational system developed to assist the FAA in air traffic flow management. ETMS is a mission-essential system that collects and uses actual traffic data for:

- tracking, predicting, and planning air traffic flow,
- analyzing ground delay effects, and
- evaluating alternative routing strategies.

The ETMS enables TMC to respond strategically to situations across the NAS rather than focus on local solutions or local data.

Notice to Airmen

Notices to Airmen (NOTAM) provide the most up-to-date information about the status of NAS resources, including the unexpected and temporary changes that will ultimately be issued as amendments to aeronautical charts and publications. For instance, runway closures, malfunctions to navigational aids, and missile launches are included in NOTAM's.

Advisories

An advisory is a message that is disseminated electronically by the ATCSCC. It contains information pertaining to the national airspace system.

Advisories are normally used for the following:

- ground stops,
- ground delay programs,
- route information,
- strategic plan of operation,
- facility outage and scheduled facility outages,
- volcanic activity bulletins, and
- special traffic management programs,

Any time there is information that may be beneficial to a large number of people, an advisory may be sent.

3.1.2 TMI and Tools

A Traffic Management Initiative (TMI) is one of several techniques used to manage traffic flows across the NAS. Non-compliance with a TMI translates into airplanes not being where and when they are expected. This manifests in unused slots that can never be filled or an overabundance of airplanes. Along with any given TMI there are a number of tools used to manage traffic flows. The following describes some of the tools available to Traffic Management Personnel for implementing several types of TMI techniques (i.e., Routing and Re-routing, Sequencing and Metering, and Capacity/Demand).

Routing and Re-routing

Traffic managers and controllers have a number of routing options to expedite the flow of traffic even during severe weather or constraints on the system. Traffic managers use altitude to segregate different flows of traffic or to distribute the number of aircraft requesting access to a specified geographic area. Low altitude arrival/departure routing (LAADR) is a set of routings with altitude expectations for use in times of severe constraints on the system. *"Capping"* is a colloquialism for planning to hold aircraft at altitudes lower than their requested altitude until they are clear of a particular area. *"Tunneling"* is another colloquialism, used for descending traffic prior to the normal descent point at an arrival airport to remain clear of an airspace situation on the route of flight. The terms "Capping" and "Tunneling" may be used in response to weather or other situations that impact the ability to provide Air Traffic Control (ATC) service. Preferred routes are requested routes that are published by ATC to inform users of the "normal" traffic flows between airports. They were developed to increase system efficiency and capacity by having balanced traffic flows among high-density airports, as well as, de-conflicting traffic flows where possible. Coded Departure Routes (CDR) are a combination of coded air traffic routings and refined coordination procedures. They are designed to mitigate the potential adverse impacts to the FAA and users during periods of severe weather or other events that impact the NAS.

In addition to the above routes, national routing initiatives are also available. These include the National Playbook and North American Route Program (NRP). The National Playbook is a collection of severe weather avoidance plan (swap) routes that have been pre-validated and coordinated with impacted air route traffic control centers. They may be used in support of convective weather, military operations, and other situations as deemed appropriate. The NRP specifies provisions for flight planning at flight level 290 (FL290) and above, within the continuous U.S. and Canada. It enables flexible route planning for aircraft operating at fl290 and above, from a point 200 nautical miles (nm) from their point of departure to a point 200 nm from their destination. Additional flexibility is available by utilizing specified departure procedures (DP) and standard terminal arrival routes that have been identified within 200 nm of the airport(s).

ATC uses re-routes to ensure that aircraft stay with the "flow" of traffic, remain clear of special use airspace, avoid congested airspace and areas of known weather where aircraft are deviating or refusing to fly. As flows of traffic are moved to avoid severe weather, the traffic that would have been on that route may be moved to manage volume issues. Normally, air traffic controllers clear a flight on a route specified by traffic management, and the re-routing may be performed in the air or the on ground.

Diversion is a flight that is required to land at other than its original destination for reasons beyond the control of the pilot or company (e.g., periods of significant weather). Diversion Recovery is a process of returning a previously diverted flight to the airport of its originally intended landing

Sequencing and Metering

Sequencing and metering provides a way to manage aircraft flow in heavily congested areas and to increase throughput at certain resources (i.e. fixes, airports). Miles-in-trail (MIT) describes the number of miles required between successive aircraft that meet specific criteria. The initiative may be applied as a separation for an airport, fix, altitude, sector, or route. MIT are used to apportion traffic into a manageable flow, as well as provide space for additional aircraft (merging or departing) to enter the flow of traffic. Minutes-in-trail (MINIT) describe the number of minutes required between successive aircraft. It is normally used when aircraft are operating in a non-radar environment or are transitioning to a non-radar environment. It may also be used if additional spacing is required due to aircraft deviating around weather. Sequencing Programs are designed to achieve a specified interval between aircraft. A departure sequence program (DSP) assigns a departure time to achieve a constant flow of traffic over a common point. Normally this involves departures from multiple airports. An En-route sequencing program (ESP) assigns a departure time that will facilitate integration into the En-route stream. An arrival sequencing program (ASP) assigns fix crossing times to aircraft destined for the same airport.

In addition to the aforementioned initiatives, Traffic Management Advisor (TMA) tools aid in sequencing aircraft to meet demand. The Center TRACON Automation System Traffic Management Advisor (CTAS-TMA) is a tool that assigns meter fix/arc crossing times to aircraft to manage airport arrival demand. TMC and air traffic controllers in the ARTCC (Center) collaboratively control arriving aircraft that enter the Center from an adjacent Center or depart from feeder airports within the Center. On the basis of the current and future traffic flow, the TMC creates a plan to deliver the aircraft, safely separated, to the TRACON at a rate that fully subscribes, but does not exceed, the capacity of the TRACON and destination airports. The TMA increases the situational awareness of Center TMC's and air traffic controllers through its graphical displays and alerts. TMA computes the undelayed estimated time of arrival (ETA) to the outer meter arc, meter fix, final approach fix, and the runway threshold for each aircraft. Furthermore, TMA computes the sequences and scheduled times of arrival (STA's) to the outer meter arc, meter fix, final approach fix, and the runway threshold for each aircraft to meet the sequencing and scheduling constraints entered by the TMC. The TMA also assigns each aircraft to a runway to optimize the STA's. TMA continually updates its results at a speed comparable to the live radar update rate in response to changing events and controller inputs.

Capacity/Demand

All resources in the NAS have a limited capacity. Part of traffic management is to balance the demand on those resources so that the capacity is not exceeded in manner that leads to aircraft delays. With a goal of equitable distribution of demand, fix balancing is a technique used to assign an aircraft a fix other than the fix filed in the flight plan for the arrival or departure phase of flight. Implemented by the Airport Reservation Office (ARO), the Special Traffic Management Program (STMP) is used to control the number of arrivals and departures from the airports that are experiencing unusually high demand levels due to special events. Occasionally, airborne holding is planned to manage a specific situation; at other times, airborne holding is in response to a specific situation and is unplanned. Controller preference to use holding is dependent on their operating environment. At some facilities where holding airspace is available, holding ensures aircraft are available to fill the capacity at the airport. In other cases, because of the airspace configuration, holding may not be practical.

Monitor Alert Parameters (MAP) are used in several simulations as a means to capture sector capacity. In the field, the MAP establishes a numerical trigger value to provide notification to facility personnel, through the Monitor Alert (MA) function of the ETMS, that sector/airport efficiency may be degraded during specific periods of time. The efficiency of a functional position or airport in providing Air Traffic (AT) services is a shared responsibility of the TFM team. That team consists of the Air Traffic Control Specialist (ATCS), Operations Supervisor (OS), and the Traffic Management Unit (TMU). These entities must monitor, assess and act on sector/airport loading issues to ensure that these NAS elements operate efficiently. The ability of a functional position or airport to provide Air Traffic Services (ATS) may be affected by a variety of factors (i.e. NAVAID's, meteorological conditions, communications capabilities, etc.); therefore MAP is a dynamic value which will be adjusted to reflect the capabilities of the functional position or airport.

High density traffic airports (HDTA) are airports with very high demand. Only five airports in the U.S. are considered to have continuously high demand that necessitates slot reservations being used at all times: John F. Kennedy International (JFK), La Guardia International (LGA), Ronald Regan Washington National (DCA), Newark International (EWR), and Chicago O'Hare International (ORD). The only unscheduled flights accepted at an HDTA without a reservation are emergency aircraft.

3.2 Traffic Flow Management Practices in Europe

The following section represents a summary of descriptions of TFM programs, functions, systems, offices and standard operating procedures as described in [6] and [8].

In Europe, the Central Flow Management Unit (CFMU) co-located at the EUROCONTROL Headquarters' Haren Center near Brussels, Belgium provides Air Traffic Flow Control Management (ATFCM). CFMU provides services within the airspace of the Member States of European Civil Aviation Conference (ECAC). In particular, as stated in [6], the CFMU principal objectives are:

- "For Air Traffic Services: the provision of flight plan data, the best utilization of available capacity, the smoothing of traffic flows and the assurance of protection against overloads.
- For Aircraft Operators: the provision of advice and assistance in flight planning and the minimization of penalties due to congestion."

ATFCM was initially developed as Air Traffic Flow Management (ATFM) service, with a goal of "contributing to a safe, orderly and expeditious flow of air traffic by ensuring that ATC capacity is utilized to the maximum extent possible, and that the traffic volume is compatible with the monitoring values declared by the appropriate ATS authority." [8] Over time, ATFM evolved into ATFCM – an ATM service with an objective of balancing the management of capacity and demand through strategic planning and tactical implementation.

3.2.1 ATFCM Phases

ATFCM is achieved through three phases, each consisting of specific activities performed within their corresponding lookahead horizon: (1) Strategic Flow Management, (2) Pre-tactical Flow Management, and (3) Tactical Flow Management.

Strategic Flow Management is a planning phase consisting of research, planning and coordination activities and occurring seven days or more prior to the day of operation. This phase aims to determine potential problems and corresponding possible solutions in ATFCM by analyzing the changes in demand forecasts. Capacity Plan, Route Allocation Plan and other plans are results from activities performed in the Strategic Flow Management phase.

Pre-tactical Flow Management is also a planning phase, but consists of planning and coordination activities and occurs up to six days before the day of operation. This phase aims to determine the best possible ways to balance the available capacity and the expected traffic flows by not only optimizing Area Control Center (ACC) opening schemes according to traffic flows in order to provide a continuum of capacity, but also by optimizing traffic assignment through the use of the strategic ATFCM pre-defined scenarios. Remaining bottlenecks at the level of sectors or airports are addressed by defining flow management measures (flow rate applied to a specific traffic volume during a certain time period). All of these activities result in the publication of the ATFCM Daily Plan.

Tactical Flow Management is a tactical planning and implementation phase that occurs on the day of operation, and consists of re-routing activities and slot allocation. This phase aims to balance the available capacity and the actual demand through real-time monitoring of the ATFCM situation, and its activities result in updates to the Daily Plan.

3.2.2 ATFCM Processes

Rerouting processes

Strategic Rerouting is one of the most important outcomes from the strategic planning phase. It is governed by the Route Availability Document (RAD), which contains Aeronautical Information Publication (AIP) routes, flow restrictions and ATFCM routing requirements, and is produced to support Aircraft Operations (AO) in their flight planning activities, as well as the CFMU in their rerouting activities. RAD is not a static document; it is continuously reviewed and, as a result, it dynamically evolves with changed conditions within the applicable airspace. Both permanent amendments and temporary changes can be added as needed. RAD can be accessed on the CFMU web site, while the changes to RAD are published via ATFCM Notification Message (ANM).

Pre-tactical routing aims to improve medium and short-term management of ATC capacity by updating/developing special rerouting scenarios that contain reroutes avoiding the areas in which a major imbalance between the anticipated demand and capacity is anticipated. These special rerouting scenarios are developed through collaboration between the CFMU and the affected Flow Management Position(s), and published either as a mandatory or as an advisory instruction via ANM and Network News. Mandatory scenarios can be applied either to a traffic flow in certain area (Rerouting Scenarios) or to a set of flight levels within a traffic flow (Flight Level Capping Scenarios); in either case, AO has to file or re-file their flight plans in response to these restrictions. Advisory scenarios, on the other hand, activate certain routes with the affected airspace that are not typically used for the same type of traffic; these routes become available for offloading traffic from other routes with the airspace with a goal of avoiding delays and better traffic balancing. However, such scenarios typically create higher traffic complexity within the affected airspace, and, thus, cannot produce significant capacity improvements. In addition, if flight plans are accidentally accepted on routes which should actually be closed, Flow Management Position (FMP) can also request an implementation of a Zero Rate Scenario; these scenarios help better manage short notice changes to the airspace structure and amendments to RAD.

Finally, Tactical Rerouting is also available as a means of identifying the instances when Strategic and Pre-tactical rerouting could be improved; it is a result of monitoring the operations as they develop.

Slot Allocation Process

Slot allocation is a centralized process that develops a Slot Allocation List (SAL) for each regulated location (point, airport, sector, etc.). Departure Slot Allocation is based on the Computer Assisted Slot Allocation (CASA) process of the Enhanced Tactical Flow Management System (ETFMS) system. CASA is a complex process consisting of several stages and procedures, and can dynamically respond to flight plans that are filed late and flight plan modifications.

CASA is governed by the “First Planned-First Served” rule. If a flight is subject to several CASA regulations, it is given the delay of the most penalizing regulation and is forced with that delay into all other regulations. This rule presumes flights should arrive over the restricted location in the same order in which they would have arrived had there been no ATFM measures. It is applied throughout the CASA process.

In addition, the True Revision Process (TRP) routinely attempts to improve the departure slots already allocated to flights. This automated process starts after the first Slot Allocation Message for a flight has been issued (2 hours before the Expected Off-Block Time) and ends a time parameter before the CTOT; this parameter varies by the Aerodrome of Departure.

Slot Adherence

Compliance with CTOT is a joint responsibility of AO and ATC. In particular, AO is required to adhere to all general and current ATFCM procedures, measures and message exchange requirements, and also account for taxi-time and, in general, time that may be necessary for other activities prior to take-off that may impact ability to meet CTOT. ATC, on the other hand, is responsible for departure slot monitoring at departure airports, including newly available slots from suspended flights, as well as assisting AO to meet their CTOT or coordinate a revised CTOT. Note that ATC has a [-5 min, +10 min] tolerance window applied to the TOT for optimizing departure sequence.

On the other hand, ATC may refuse to issue a start-up clearance to a flight that cannot meet its CTOT until a revised slot is issued. Such revisions are typically coordinated between the affected AO and CFMU; sometimes though, when direct communications between the pilot and ATC are already established, the revisions may be coordinated with CFMU through ATC.

Position Reporting

Accurate and timely position reporting is critical for achieving efficient ATFCM. Current aircraft positions and limited information about the current state and future route of the flight are collected and disseminated through ETFMS. Prior to departure, AO is required to send a delay or a modification message if unable to adhere to its slot. Once airborne, radar derived positions will be regularly reported for the flight, as well as some special messages informing CFMU about significant events affecting the flight. Augmented by the wind and other relevant information about the operating environment, flight position reports and special messages are normally sufficient for CFMU to estimate flight profiles and their ability to adhere to the assigned slots, and to revise the flows as needed to respond to forecasted demand and capacity imbalances.

Management of Unusual Situations

Normal operations can be affected by various events that make it difficult or even impossible for flights to meet their assigned slots. For instance, these may be low visibility, closure of airports or airspace, or adverse operating conditions at airports such as emergencies, equipment failures and extreme adverse weather conditions.

In instances of low visibility at an airport, a Runway Visual Range (RVR) value is published; all flights that can land under such or lower RVR values will be allowed to take-off and proceed towards this airport as planed, while other in-bound flights will have to wait for better visibility conditions. However, in order to avoid excessive airborne holding, even the flights that can land under such poor visibility conditions may be delayed as needed.

On the other hand, if an airport is going to be closed for a longer time, flights will be suspended; otherwise, flights will be delayed as needed to depart or arrive when the airport opens for operations again. These generic rules may also apply in the case of strikes, but would be adapted to specific local conditions.

Finally, if the conditions at an airport deteriorate below the conditions necessary for meeting accepted CTOT's, ATC/Tower has to coordinate with CFMU through FMP to determine alternative solutions and obtain new CTOT's.

3.2.3 Collaborative Decision Making

CDM is a process used by CFMU, ANS Provider (ANSP's) and AO's to act upon the most up-to-date ATFCM information and dynamically adjust and optimize flights' 4D trajectories. AO's are involved in CDM through the AO Liaison Officer (AOLO) and AO Liaison Cells. AOLO is a new position composed of EUROCONTROL/CFMU personnel who have AO experience; they are involved in pre-tactical and tactical decision making by contributing to preparation and updates of ATFCM Daily Plans. AO Liaison Cell, on the other hand, consists of air carrier representatives in the CFMU organization that are responsible for providing a focal point between CFMU operational services, AO's and ATM providers. They are involved in both strategic and tactical activities, as well as in monitoring the equity of the flow management process.

3.3 Future TFM Concepts

Multi Sector Planner

MSP is a proposed air traffic controller position that aims to provide for improved and more efficient traffic flows in a managed airspace [9] - [11]. The roles and responsibilities of MSP and the interaction with other air traffic controllers at all levels or within all layers of traffic control are still being investigated and are in development. Several R&D efforts are currently being conducted with a goal of examining the best and most efficient ways of introducing such functionality. For instance, FAA is working with NASA, San Jose State University, and others to determine the exact tasks MSP should be in charge of, as well as the coordination requirements between the sector, TFM, and other controllers. EUROCONTROL has also started investigating the same issues, in particular within its PHARE and Gate-to-Gate projects. Although there are differences in terminology, planning horizons, and other details specific to implementations being addressed by FAA and EUROCONTROL separately, MSP is generally being investigated as (1) a Multi-D controller, and (2) an Area Flow Coordinator.

MSP in the role of a Multi-D (or a Super-D) controller is responsible for providing support to several R-side air traffic controllers. Aided by improved communications and automation, an R-side controller can be assigned some of the tasks typically performed by a D-side. That leaves the D-side with a reduced task-load, which further creates an environment in which a single D-side controller can support several R-side controllers; therefore, such a position is titled Multi-D or Super-D controller. The roles and responsibilities of the Multi-D controller are envisioned to consist mostly of pre-planning and coordination for all of the managed sectors, but in cases of high traffic demand or severe weather moving into the managed airspace, Multi-D controller could start supporting a specific (most negatively affected) R-side controller more actively than the other R-side controllers; as a result, in such specific instances, the role of the Multi-D controller could transition back to a current D-side support.

MSP in the role of an Area Flow Planner is tasked with resolving strategic flow issues over the several sectors within its managed airspace. Such a controller has no tactical control of operations; in fact, Area Flow Planner is envisioned to keep solving TFM-like problems within much smaller (local) area of its responsibility. In addition, Area Flow Planner would also provide coordination support between the TMU, R-side controller and other adjacent Area Flow Controllers.

Dynamic Sectorization

Dynamic sectorization is a new concept that allows dynamic adjustment of airspace configuration as best suited to balance sectors' traffic complexity and controllers' workload.

Generally, it is assumed that the sectorization and all possible ACC configurations are defined during the strategic phase (i.e. several months ahead of operations) since this interacts with standard traffic assignment and pre-defined scenario elaboration. Each sector can consist of several elementary airspace pieces in order to cope with specific traffic flow patterns. This flexible re-sectorization ability can be used during all the ATM phases, but in-particular during the real-time assessment of instantaneous controller loading (based on occupancy count) or according to traffic complexity monitoring from 40 minutes to 2 hours before sector entry time. This capability is already available today, and is used to combine sectors for the night shift and during peak workload conditions. Currently, research is underway to investigate how extensible this concept is to a more dynamic set of sector boundaries. Sector boundaries have been implemented for many reasons across sectors (e.g., radio and navaid coverage, routes) and designing even more flexible boundaries will need to consider these variables.

Use of dynamic TFM/ATFCM measures such as Miles-in-Trail, or re-routing, or flight level capping are envisioned as complementary measures to dynamic re-sectorization.

4 Current TFM Modeling Capabilities

Capabilities of the existing fast time TFM tools were investigated via a web-based survey. The survey was developed using the phpESP open source software package that supports building and managing surveys through a web interface. The base software package was enhanced to provide for some additional features such as specific question types, and response collection and storage.

The questions were driven by the objective of determining the ability of the existing fast-time TFM tools to mimic the actual TFM environment and operations. The focus was placed on both the current modeling capabilities and the ability to adjust those as needed to successfully model selected future TFM concepts. The participants were asked to provide comprehensive information about the investigated tools, including general characteristics such as: hard-coded and user-specified input parameters; logic implemented to mimic TFM initiatives, planning horizons and operations; recorded outputs and metrics, and animation and display capabilities. The survey and the questions are briefly described below; for more information, please refer to Appendix A.

4.1 Survey Description

The questions were organized into four major sections: (1) General characteristics of a tool; (2) Planning and Coordination; (3) Inputs and Logic; (4) Outputs.

Section one was designed to provide a better understanding of the technical specifications and requirements for using each of the surveyed tools. For instance, the participants were asked to provide information about the type of model each tool is based on (discrete event, continuous, agent based, analytical or other), the tool's primary purpose and high level objectives, the platform (PS or WS) and the operating system, any special technical requirements, and the amount of time a typical user would need to create and run an application and generate outputs (minimum, average, and maximum time estimates).

Section two addressed the TFM planning and coordination related modeling capabilities. First, the participants were asked to provide information about the magnitude of the planning horizons that can be modeled and the related activities. Then, they were asked to identify the actions that can result from flight re-planning, both prior to take off and in-flight, including changes in flight trajectory and departure time, or flight cancellation.

Section three was designed to provide a better understanding of the fidelity of the investigated tools. The participants were asked to provide information about the inputs required by each of the tools; among others, these included flight schedules, flight plan information (by field), initial flight trajectories, uncertainty in flights' 4D positions, various costs that can be used to evaluate efficiency of possible TFM measures (overflight fees, unit costs of delay, capacity, etc.), and various TFM initiatives, such as MIT, MINIT, and re-routes. The participants were also asked if any of the control parameters could be user-specified (as opposed to being hard-coded or even unavailable) and dynamically changed during a run. In addition, numerous questions about the logic implemented to mimic TFM actions, processes and operations were also addressed in this section. For instance, the ability to model various TFM initiatives and to implement these initiatives based on the geographic boundaries of the managed airspace (tiers or TFM areas); aircraft-to-aircraft separations; equipage-based performance and separations; aircraft performance characteristics including fuel burn; re-routing due to weather and traffic congestion; limitations due to sector capacity, MAP, shape, size and routing patterns; limitations due to airport capacities; limitations due to active special use airspace; limitations created by severe weather cells (location, shape, size); dynamic sectorization; 4D contracts; and multi-sector planning.

Section four contained questions about the type of outputs the investigated tools produce, and the metrics they calculate. In addition, the participants were asked to provide information about the tools animation and output display capabilities. The survey ends with questions about the type of studies the tools have been used to conduct and the improvements that would enhance TFM analytical capabilities for current and future concepts.

4.2 Survey Results (Current Capabilities)

4.2.1 General characteristics of the surveyed tools

The survey was completed for 24 tools that could be used to investigate various aspects of TFM processes. Most of the tools are discrete event fast-time simulations or analytical tools (q. 2)[1]. In addition, a few of the tools are developed as agent-based models or as continuous (time-based) models. Most of the surveyed tools are designed as fast-time simulation or analytical tools. Only one of the surveyed tools is a real-time simulation, and another one is capable of running as either a real-time or a fast-time simulation.

The surveyed tools can be generally grouped into three types of models (q. 2, 24-26, 54-56, 66-68). Some tools are designed as queuing models, and typically work with either flight schedules or departure times and route information. These tools view a route as a list of resources that flights will go through and times they will needed to use or traverse them.

Other tools work with flight schedule and flight plan information to determine changes to the planned 4D trajectories by considering both capacity limitations and the geometry of sectors and paths flown. Some of these tools, however, do not use detailed route information provided in the flight plans, but only the aircraft type, origin and destination airports, departure and arrival times, and, infrequently, initial cruise flight level and equipage on-board. Tools that do not implement the filed flight trajectories typically work with the great circle route, wind optimized great circle routes between the airports of origin and destination, or the actual flown flight trajectories.

Finally, the third group of tools goes further and accommodates air-carrier decision making by considering air-carrier strategies regarding scheduling, operational procedures, and disruption recovery (q. 20, 24, 29-32, 87).

Most of the surveyed tools were designed to investigate resource utilization planning and congestion management, and for post-operations analysis (q. 3, 10-15, 87-88). Other tools

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[1] Throughout the section *4.2 Survey Results (Current Capabilities),* numbers in parentheses indicate the principal questions used to assess the capabilities being described (please see the Appendix A). Note that in addition to the answers to these questions, answers to other questions may have also provided clues about each discussed capability of a tool.

focus on human performance and workload, safety (risk assessment as a function of capacity), or on investigating the impact of air traffic operations on the environment.

4.2.2 Planning and Coordination

The long-term and medium-term TFM research, planning, and coordination activities that take place one to many days prior to the day of operation are not covered by the current modeling capabilities (q. 10-11, 15, 38, 55, 68). However, many tools have the capability to simulate forecasted flight plans and to investigate new airspace sectorization schemes and their impact on traffic flows. More precisely, these tools typically utilize "what-if" or "trail and error" approaches to determining relative efficiency of a set of different solutions/implementations as opposed to directly determining optimal routing or sectorization schemes. In other words, different implementations need to be independently modeled and then compared in order to determine relative benefits of one implementation over the others.

Short-term TFM planning and coordination activities are also not well represented in the surveyed fast-time TFM modeling tools (q. 12-20, 38). However, the majority of the surveyed tools support modeling the impact of these activities. In fact, a range of capabilities mimicking the real-world TFM implementations with varying levels of fidelity is typically present in all of the surveyed tools. These include changes to departure times based on the observed airport capacity, capabilities to model slot allocation schemes, ground delay and ground stop programs, route or waypoint in-trail restrictions, and changes to flight routing based on sector capacities or MAP values and other restrictions such as National Playbook or RAD routes. Typically, the lookahead horizon for planning decisions is up to 6 hours.

Many of the surveyed tools have conflict detection capabilities (q. 21-23, 38-39, 47-49). However, in some cases these are simply being recorded for workload or sector congestion estimation. Tools that do have conflict resolution capabilities sometimes use delay at a resource (queue modeling approach) to provide for separation assurance, and do not consider the geometry of the flown trajectories (even during arrival to, or departure from, an airport). Typically, the lookahead horizon for ATC decisions is 20-30 minutes, but not longer than an hour.

4.2.3 Inputs and Logic

As previously mentioned, modeling the impacts from various TFM activities and implementations is the primary focus of the tools investigated in this survey. Some of the tools focus on the airport while others focus on airspace flows and capacity constraints. A few tools were actually designed with a different objective in mind, but did support modeling impact of at least some of TFM implementations. For instance, some tools were actually developed to support system-wide assessments of the impacts of new air traffic management technologies, concepts, and policies. Other tools were developed to support predicting controller workload and the impact of the controller's workload on capacity and efficiency of en route sector flows, and some others to support capacity related decision-making under uncertainty and high congestion levels. All these tools, however, do have something in common; they are being used to better understand the efficiency of TFM decisions and operations.

One of the most significant impacts a TFM implementation can have on observed flights is a change in their planned trajectories (q. 16-20, 26-32, 50-51, 71). Most models have a means of modeling such impact, but levels of fidelity are quite variable. Some tools can change only temporal aspects of a flight plan, while others consider available routes and location of severe weather cells. In most cases these changes are made as a response to traffic congestion in an airspace resource or at an airport resource, or as a response to a capacity decrease due to weather. In addition, some tools integrate the capability to model the impact of air-carrier decision making and also to consider network operations and connection times between successive flights (legs) of the same airframe when determining flight delays. However, some of the tools can re-route a flight only before its take-off; once the flight is airborne, only the temporal aspects of its adopted flights plan can be modified. In other cases, the capability to dynamically change flight trajectory is developed, but is limited to user specified inputs, as opposed to being determined by the tool itself.

If a delay for a flight reaches an intolerable level, some tools will cancel the corresponding flight (q. 18, 20, 29-30, 32-37, 69-72). This is typically a consequence of reduced capacity of the observed system, and may be caused by a lack of available routing or by an extended ground delays (both are, of course, pre-departure considerations). Capability to model flight cancellations is also implemented by using a probability of cancellation applied to each flight or a selected group of flights, or by simply removing flights from an initial schedule as specified by the user (input specification) or as indicated by the actual traffic data used in a particular simulation. In most cases, this is a pre-simulation activity, but a few tools can actually support dynamically changing input specifications during a simulation run.

A capability to determine flight priorities and potentially swap slots or trajectories between flights also exists (q. 32, 69-70); in some cases, though, it was identified as not thoroughly tested and validated. Such slot/trajectory swapping is typically done with a goal of improving flight efficiency of a “more important” flight. For the most part, the participants did not elaborate on information about how relative importance is determined; the only exception to this was a capability to implement flight priorities by specifying an optional list of flights having a higher priority. Also, it is unclear if flight swapping is or could be limited only to the flights performed by the same air-carrier. For one of the tools, this capability may have been implemented through use of an airline agent to optimize flights by altering their slots and trajectories, which if the agent is air-carrier specific, then flight swapping could be limited only to the flights performed by the same air-carrier. However, if the agent is a generic air-carrier agent used for all of the carriers flying during an investigated scenario, this capability would not be supported. The participants identified flight cancellations and trajectory swapping as relatively easy to implement and planned for future model improvements in this area (but did not comment on exclusiveness of the implemented logic to a specific carrier).

The capability to model diversions to other airports is currently not well represented (q. 31). Only two responses indicated that this capability was modeled, but no explanation on the corresponding logic was provided. One of the surveyed tools does have a capability to switch a flight to its alternate flight plan during the simulation, but has no means of recovering the flight back to its original airport if conditions change.

Uncertainty in flights’ 4D positions or their ability to meet expected times of arrival to a waypoint are currently not directly modeled (q. 27-28, 74). In other words, uncertainty is "implemented" through adjusting flight times as needed for separation assurance, but not through actually modeling uncertainty of aircraft maintaining the proper speed, or heading, or flight level, or any other parameter that can impact its ability to meet the planned time of arrival to a waypoint, boundary crossing, or an airport. However, the capability to model departure time uncertainties is implemented in many of the surveyed tools, but does not incorporate the uncertainty in meeting the exact departure times due to variations in taxi-times, gate push-back times, etc. Only one of the surveyed tools was identified as capable of considering uncertainty of flights' 4D positions, but no details were available about the corresponding modeling logic.

Similarly, non-compliance with a traffic management initiative is not currently modeled (q. 28). More precisely, some tools have means of detecting non-compliance and even model compliance with a user-specified probability; however, they do not have mechanisms to correct the unexpected behavior. For only one of the tools, it was indicated that modeling non-compliance with a higher fidelity may have been implemented, but details were not available to determine exactly what this capability involves.

The capability to consider cost-efficiencies of the possible TFM measures is integrated in several of the surveyed tools (q. 29). These include unit cost of delay, unit cost of flying an extra mile, overflight fees and capacity unit costs. While other tools have the capability to investigate the cost of operations via post-operations analysis, the aforementioned tools can actually utilize less costly or more efficient solutions for investigated flights or scenarios.

The capability to implement MIT and MINIT restrictions are well represented in the surveyed tools (q. 33, 72). In most cases, the participants identified MIT as being applicable to either aircraft-to-aircraft separations or a waypoint, and MINIT to aircraft-to-aircraft separations, a waypoint, airport of origin or destination, altitude, sector or route.

The capability to model en-route sequencing is typically implemented through adjustment of departure times (q. 36). The capability to model arrival sequencing also exists and is typically implemented by a runway, a meter fix or an outer fix, and in few tools by meter arc (similar to TMA) (q. 34). Similarly, the capability to model departure sequencing already exists, and is typically implemented by a fix, a route, or an airport (q. 35). The survey also revealed that the capability to model arrival sequencing to two or more runways with dependant operations and multiple departure sequences feeding one or several blocks of airspace/sectors are already developed. It didn't, however, reveal if these tools implemented the capability to also consider runway or airport arrival and departure management as an integral part of arrival and departure sequencing logic, respectively.

Only a few tools, typically based on the multi-agent modeling approach, are capable of modeling CDM interaction (q. 38-40). These tools are capable of modeling system interaction based on the actions and messages exchanged between the actors that could impact the way the observed system is functioning; these may include pilots, controllers, traffic managers and AOC/dispatcher. In most cases, however, only the impacts from their actions are modeled, and neither the corresponding communications nor the workload generated. This typically results in instantaneous processing and implementation of decisions, which may affect the fidelity of the outcomes from simulation. It is important to point out that there is an exception to this statement; several of the surveyed tools indicated a capability to model workload, usually controller and/or pilot workload. However, the responses indicate that full integration of human and system performance capabilities is not currently achieved.

Most of the surveyed tools have ability to differentiate aircraft with different performance characteristics (q. 41-45). Aircraft performance characteristics are typically based on lookup tables providing data for a specific classification typically based on engine types (jet, turbo-jet, prop, turbo-prop, etc.), or individual aircraft models. Some of the surveyed tools integrate a capability to determine fuel consumption for a flight, typically calculated by taking into account aircraft classification, speed and/or altitude, and wind, and, in few isolated cases, phase of flight. Aircraft speeds, on the other hand, are typically determined by considering phase of flight, wind, altitude, and, in some cases, the performance envelope in terms of climb/descent and acceleration/deceleration rates. Quite a few of the surveyed models implement some or all aircraft performance characteristics as modeled within EUROCONTROL's Base of Aircraft DAta (BADA) database.

Depending on their primary focus, the surveyed tools are capable of considering different sets of aircraft separation standards (q. 46-49). Tools that focus on airport operations typically distinguish between separations applicable during final approach, landing and take-off. Tools that focus on airspace operations typically implement either a generic separation standard used in domestic airspace during the cruise phase of flight, or are actually capable of distinguishing between separations used in terminal areas, at an airport and domestic en-route. In both cases, tools can typically distinguish between lateral, longitudinal and vertical separations applicable between individual flights. A few of the tools can also implement different separations standard in oceanic airspace. In addition, in few cases tools are even capable of implementing different separations standards as a function of aircraft equipage (RNP, CPDLC, ADS, etc.). Details regarding this capability are not available at this time; for instance, it is still unclear if tools use a conservative approach and implement the more stringent separations between two observed flights (standard based on the equipage of the aircraft that has poorer performance).

During normal operations aircraft are rerouted in response to weather and/or traffic congestion. Most reroutes are tactical; however certain pre-defined strategic routes are also used to redirect traffic around weather and/or congestion. Many of the tools surveyed did not have a rerouting option for any of the specific options listed (q. 50). ATC preferred routes, National Playbook or European rerouting scenarios, coded departure routes, Standard Instrument Departure (SID), and Standard Terminal Arrival Route (STAR) were available in a few of the tools. However, only two tools changed the routes dynamically, while most route assignments occurred during input preparation. The use of capping, tunneling, low altitude arrival/departure routing, conditional routes, and Area Navigation (RNAV) were not available in many of the tools. Those that did have this capability were implemented by input parameters for individual flights. Some of the tools also implemented a capability to model oceanic routes and re-routing, including oceanic flexible, user preferred, or fixed routes. These reroutes occurred during input and were not dynamic. The ability to reroute on a tactical level was found in very few models. Of the models that had this capability, only three were able to perform them dynamically. A second question involving additional rerouting options was asked to capture any options missed in the previous question (q. 51). One tool mentioned a TFM algorithm that handled the reroutes, but the logic behind this algorithm was not described. Another was also capable of injecting re-routes into the system dynamically during a simulation through an external actor (user).

The capability to model aircraft holding was implemented in about half of the surveyed tools, but only a few handled holding in a similar manner (q. 52, 57). Some tools initiated holding because of sequencing or a TFM function, while others initiated holding due to exceeding sector capacity, exceeding fix capacity, exceeding runway capacity, or spacing provided for weather. A few of the tools only allowed holding as part of the initial trajectory and therefore were not dynamic. Some tools performed the holding in either the en route, terminal, or airport environments.

Nearly all the tools surveyed defined sectors by shape, location, and altitude (q. 53-57). Sector capacity was also considered in nearly all the tools and, in most cases, could be changed during a simulation at pre-specified times. Only two of the tools surveyed allowed for a change in sector capacity dynamically based on weather and traffic situations. One tool that considered workload determined sector capacity heuristically by maintaining the highest acceptable level of workload. Almost all of the tools that considered sector capacity calculated sector demand against sector capacity. The action taken when demand exceeded capacity varied by tool with either en route delay or ground delay being the predominate choices. Re-routing, increasing the separations, determining other types of user specified actions, and removing flights were among actions typically considered by some of the surveyed tools; one tool would adjust controller workload leading to a change in performance (for instance, a decrease in performance would lead to separation violations, late handoffs, and poor execution of TFM initiatives). In addition to sector capacity, the MAP values were considered in most of the tools used in the U.S. Almost all of the tools in the U.S. equated the MAP values with sector capacity. The actions taken when the MAP values were exceeded were equivalent to when sector capacity was exceeded. SUA was considered in a third of the tools surveyed; however very few modeled the on/off activation status of the SUA.

A final airspace question dealt with implementing TFM initiatives in certain areas (i.e. geographic tiers, TFM areas) (q. 60). About a third of the tools surveyed applied the TFM initiatives when departing from an airport, landing at an airport, or transitioning through an area. One tool performed TFM initiatives globally, but indicated that it could be customized for local levels.

As one of the leading factors in flight delays, severe weather has been an important issue for TFM practitioners and model developers alike. The results of the survey indicate that the research and development in the area of severe weather modeling needs to continue in the future (q. 61-63). Of the tools that did consider severe weather, most model it only as reduced capacity dictated by the inputs to a simulation. Only two considered the location and shape of the weather cell and modeled dynamic cell movement. The source of weather data varied as much as the models that considered weather. The following is a list of weather sources: National Center for Atmospheric Research (NCAR), European Centre for Medium-range Weather Forecasts (ECMWF), Public Information, Pacific Northwest Mesoscale Model (MM5-1), Next-Generation Radar (NEXRAD), Corridor Integrated Weather System (CIWS-1), Rapid Update Cycle (RUC-1), National Convective Weather Diagnostic (NCWD), CCFP, and National Convective Weather Forecast Product (NCWF). A few of the tools also allowed for user defined shapes of weather cells. In response to severe weather, operations can be rerouted, slowed (increase in-trail restrictions), or stopped (GDP, GS). Only four of the models surveyed allowed re-routing around weather. Also, four of the models surveyed adjusted the MAP or capacity values to show the impact of weather. Only three tools considered de-icing (q. 64).

Airports can be modeled in a number of ways, but for the most part airport capacity is the key factor (q. 65-68). Most of the tools surveyed determined airport capacity in some way; either as an input parameter for individual runways, an input parameter for the whole airport, or they distinguished between departure and arrival airport capacity. Only three of the survey responses determined airport capacity by processing flights. These three tools were detailed airport models. The responses to the survey showed that of the tools that modeled airports (66% of the surveyed tools), most could model an unlimited number of airports. However, these airports were mostly sink/source airports and not created in high detail. The evaluation of airport demand and capacity was available in all the tools that modeled airports. When demand exceeded capacity, most of the tools imposed a delay (gate, ground, or en route). A few either placed aircraft in queues, eliminated flights, adjusted departure times, imposed flow metering, applied holding, or implemented a GDP.

There are TFM programs that assist in the management of a severely constrained system. These programs are usually implemented when all other options have been considered. GDP and Slot Allocation (SA) are two such programs that can occur during severe weather conditions. About two-thirds of the responses indicated they triggered these programs based on weather at the destination airport or weather en route (q. 69). Other triggers included; a TFM algorithm, scheduled event, user specified event, airport or airspace capacity exceeded, and a ration-by-schedule (RBS) algorithm. GS and Tactical Departure Slot Allocation (TDSA) are programs implemented during reduced capacity (q. 70). The surveyed tools typically trigger these events based on reduced capacity due to weather below user arrival minima, severe weather on routes, major equipment outages, catastrophic events, precluding extended periods of airborne holding, precluding sectors from reaching saturation levels, and precluding airports from reaching gridlock. One tool modeled historical or user submitted GDP/GS implementations.

TFM restrictions are used both tactically and strategically in order to control the flow of traffic in the system. The surveyed tools either implemented airport slot control, GDP, GS, Map Values, MIT, or MINIT restrictions (q. 72). However, many of these restrictions were performed differently based on the tool. Airport slot control, GDP, and GS were found in less than a third of the models surveyed. Map values, MIT and MINIT were found in slightly more than half the tools surveyed. The capability to model these restrictions in a variety of different ways were identified: hard-coded, user-specified, different for different resources, able to change during a run, automatically triggered by the tool according to traffic development, and/or automatically triggered by the tool according to weather development. This indicates that the tools surveyed provide a number of different options to the practitioner.

The capability to change airspace sectorization is implemented in several of the surveyed tools (q. 73). This capability is accomplished through either dynamic construction of new sectors or reconfiguration of the predefined (static) sectors. In most cases, it was pointed out that dynamic sector reconfiguration can only be implemented according to user specified schedule and scheme. It was unclear if any of the surveyed tools have a capability to actually determine a globally optimal sectorization scheme for a given period of time, and weather and traffic forecasts.

The capability to model 4D contracts is implemented through modeling 4D trajectories (q. 74); however, the survey did not identify a capability to manage non-compliance with a planned 4D trajectory (contract). Note that for only one of the tools was it indicated that managing non-compliance with a planned 4D trajectory may have been implemented, but details were not available to determine the exact implementation of this capability.

The capability to model the Multi-sector Planner function is implemented in only one of the surveyed tools (q. 75-82). This capability is described as flexible and supports modeling the MSP role as either a Multi-D or a local TFM controller; in both cases, specific tasks could be specified and assigned to an MSP, who coordinates with all R-side controllers in its assigned area. However, it is important to point out that the same tool was described as not having a capability to model the actions or the workload of the R- and D-side controllers, combined R- and D-side controllers, global/network traffic manager or local traffic manager; therefore, it is still unclear how the capability to model MSP is actually implemented. The literature survey revealed that this tool integrates high-level models of cognitive human performance, but no explicit details on their exact capabilities or performance were found. Also, the participant providing inputs about this tool did indicate that MSP modeling capability has not been used in previous studies.

Finally, the survey revealed that the capability to asses the impact of air traffic operations on the environment is developed and implemented either within a separate tool or as a module that could be integrated with an existing TFM tool (q. 84); with this capability, the following emissions can be modeled: CO_2, SOx, H_20, NOx, CO, HC, VOC, TOG, and PM.

4.2.4 Outputs

Most of the tools surveyed produced various statistics for flights, sectors, airports, and individual resources (i.e. fixes, routes) (q. 83). This coincides with the fact that many of the tools are used for resource utilization and efficiency, and cost/benefit analysis. Simulation logs provide information on individual events that happen in the simulation. These types of logs can be used for producing statistics not found in the models standard reports or debugging. Many of the tools surveyed produced simulation logs. Statistics on emissions were only found in one model. Although emissions are an important issue, most of the models surveyed deal with cost/benefit and operational issues rather than environmental issues. Fuel burn, on the other hand, is an environmental metric that gets more mention than emissions due to its association with operational costs. Another statistic that appeared in one model was AOC activities. This is directly related to TFM and should probably be found in more models in the future.

Approximately one half of the tools surveyed calculated capacity and delay metrics (q. 84). This reflects the fact that most of the tools are system performance tools. Efficiency, complexity, environment, and predictability were calculated in about a third of the tools. Although metrics that relate to conflicts, workload, demand, and separations were not specifically mentioned on the survey questionnaire, these metrics were added to some of the responses; thus, these metrics may have been found in more of the surveyed tools if each of them was a specific choice offered in the survey questionnaire. Among them, workload is one metric that needs further research. The cost and time to develop and execute real-time human-in-the-loop (HITL) simulations increases the need for fast-time simulation to perform controller workload evaluations.

Graphical displays provide a means to show detailed output in an easy to understand form. Animation provides a means to play back the simulation for validation and debugging. These display tools are found in most of the tools surveyed (q. 85-86).

As mentioned above, most of the tools surveyed are system performance tools. These tools are used mainly for cost/benefit analysis and operational performance evaluation (capacity and delay) (q. 87). A few of the models also identified capabilities for specific studies; network analysis, optimization, conflict and detection technology, future traffic analysis, and procedural development. Only one model surveyed assessed controller workload.

The practitioners' were asked to respond to two questions related to improvements to their tools and when these improvements are likely to be implemented (q. 88-89). Only one response indicated that no improvements were planned. About a third of the responses indicated that more substantial enhancements to the current capabilities are planned in near future. Two common areas of planned improvement were dynamic rerouting and more detailed modeling of en route weather, including the ability to model dynamic severe weather cells. These improvements go hand in hand as many of the practitioners indicated during the TIM that dynamic rerouting around weather cells was a requirement for concept analysis. A couple of the survey responses indicated that an airport model would be added to their tool. Most of the other improvements were in specific areas, such as addition of various TFM functionalities, addressing the Next Generation Air Transportation System (NGATS) considerations, real-time navigation and guidance, fuel consumption, operator decision-making, AOC decision-making, controller functionalities, environment modification, and Flight Management System (FMS) functionalities. All of these improvements have been identified in the past as necessities; about half of these improvements are planned to be completed within the next year.

5 Gaps in TFM-related Modeling Capabilities

The responses to the survey described in the Section 4.1, *Survey Description*, reveled that the capabilities supporting an assessment of forecasted or actual resource utilization, and flow and flight efficiencies are already developed and implemented in numerous tools. However, we still do not have means of determining how well the system actually did perform on a given day compared to the optimal system performance. Current modeling capabilities do not extend to an investigation of the system-wide optimal TFM solutions that comprehensively investigate all of the re-routing and ground delay options as used in the real system. As a result, an assessment of how the system performed on a given day as compared to another day is possible. Similarly, some insights can be gained as to how the system should be run for a given traffic and weather forecasts. However, we still cannot successfully determine how much of the performance achieved on a given day could have been better; the only way to achieve this would be through the development of a “what-if” approach.

In addition, there is no connectivity between the human performance and system performance models. System performance is affected by the human performance, which cannot be accurately captured through capacity limitations alone. This also addresses another gap – capabilities to model future TFM concepts, which will require an integration of human and system performance capabilities. Also, it affects the fidelity of simulation outcomes, since the underlying assumption is that controllers and pilots react both instantaneously and accurately. This area deserves considerable attention relative to the assessment of alternative future concepts that involve the reallocation of roles and responsibilities between the air and ground.

Also, the responses indicated that there are still some capabilities that were not developed to the desired level of fidelity. For instance, holding patterns, uncertainty in flights’ 4D positions, non-compliance with a specific TFM initiative or a 4D trajectory contract, shape and movement of severe weather cells, dynamic and automated response regarding flights’ re-routing around such impacted areas are still not modeled to the desired level of fidelity. Modeling such capabilities more accurately is especially important due to their significant impact on traffic interactions, and, thus, controller workload (both ATC and TFM flow manager positions), as well as on the efficiency of the TFM operations.

An important aspect in normal operations is the ability to re-route traffic around other aircraft and airspace during conflicts. In addition, one of the roles of TFM is to provide re-routes around severe weather and areas of traffic congestion. Just a few of the surveyed tools allowed for such dynamic decision-making and changes, especially in terms of the ability to generate them by the tool itself rather than to expect them to be provided by the user.

When areas become too congested with traffic, aircraft holding is an option used by controllers to temporarily relieve the workload. Although aircraft holding was found in many of the tools, there was no standard for initiating holding. Also, very few of the tools modeled holding patterns.

Sector capacity is used in many of the tools surveyed and, in the tools designed to support the U.S. TFM operations modeling, MAP values are used as equivalent to the sector capacity. The problem with using these values is that they are usually generated by the facility that controls the sector and are not based on objective measures of sector geometry and the complexity of the flows within the sector. Further research should be considered in the area of more objective sector capacity measures to allow automated calculation of these values based on the existing traffic and weather situation in the observed sector. Additionally, dynamically changing sector capacities during severe weather and/or certain traffic conditions was not found in many of the tools. A predictive measure, such as dynamic density, has been suggested as a means to address this problem.

The capability to model programs, such as GDP, SA, GS and TDSA are already developed and implemented in many of the tools with various degrees of fidelity. However, these programs are usually implemented as a last resort after other TFM initiatives have been considered, as opposed to comprehensively considered together with other TFM initiatives and programs. In fact, it is often the case that tools having capability to model these programs with higher fidelity have limited ability to simulate multiple aspects of the TFM process taken together.

The responses also revealed that fidelity and capabilities of some models could be significantly improved by linking them to some other models; however, this is not always easy or even possible due to different operating systems or other technical requirements for using these tools.

Finally, it is important to point out that even though many of the necessary capabilities to realistically model TFM processes and the corresponding impacts are already developed, they do not live within a single tool; this observation, as well as all other observations offered within this report, is limited to the 24 of the surveyed tools.

6 Summary and Recommendations

The objective of the TIM and subsequent survey was to "Identify the current and future state of Traffic Flow Management in Fast-Time Simulation". This was achieved by focusing on the following three areas: 1) survey existing model and methods for TFM, 2) identify future TFM concepts that might be considered for fast-time modeling, and 3) assess whether existing models can be extended to address these future concepts.

Survey existing models and methods for TFM

Two surveys were developed to capture the TFM capabilities that currently exist in models. The first was a short high-level survey distributed at the 2005 AP9 TIM. This survey identified some of the capabilities and allowed the subject matter experts to list future capabilities for assessment. The second was a longer more detailed survey that identified a broader range of TFM modeling capabilities.

The responses to these two surveys revealed that many of the capabilities needed to model TFM operations and the corresponding impacts are already developed and implemented. In short, these include:

- Capabilities to model changes to departure times, slot allocation schemes, ground delay and ground stop programs, route or waypoint in-trail restrictions, and changes to flight routing subject to airport and sector capacities (or MAP values), weather and other restrictions such as National Playbook or RAD routes,
- Capabilities to consider applicable separation standards and provide conflict-free trajectory modifications, and capability to differentiate between performance characteristics of typically flown aircraft types or models.
- Capability to investigate various "what-if" scenarios, including new airspace sectorization scheme, new routing schemes and restrictions, significant changes in demand, etc. (note that all of these "what-if" scenarios are founded on the assumption of *unchanged behavior* of the users and the ATC/TFM service providers),

However, differences in modeling objectives, logic and modeling approach limit the fidelity of the observed tools. In short, the following insufficiencies in capabilities were identified:

- uncertainty in flights' 4D positions and their ability to meet expected times of arrival to a waypoint/airport,
- realistic modeling of a non-compliance with a traffic management initiative,
- sector capacity as a function of controller workload, geometry of the flown trajectories and current operating conditions, and capability to dynamically adjust sector configuration,
- dynamic flight re-routing subject to a realistic severe weather movement and other changes in sector capacity,
- considering flight trajectory or slot swaps between flights with the same characteristics (same carrier, same equipage or performance level, etc.),

- capability to model realistic holding patterns, airport fix balancing and sequencing schemes,
- capability to model realistic flight cancellations and diversions, and recovery to original flight plan subject to operating conditions, and
- capability to determine system-wide optimal TFM solutions as a way of measuring effectiveness of implemented solutions.

Finally, the results also reveal that even though many of the necessary capabilities to realistically model TFM processes and the corresponding impacts are already developed, they do not live within a single tool; this observation, as well as all other observations offered within this report, is limited to the surveyed tools and is primarily formed based on the opinions and insights provided by the participating subject matter specialists and the literature review.

Identify future TFM concepts that might be considered for fast time modeling

Based on discussions at the 2005 AP9 TIM and the responses to the survey, CDM and automated CDM were identified as key concepts continuing to enable TFM operations in the future, and, consequently, as a capability that should be integrated into TFM tools to provide for more accurate modeling of current and future TFM concepts. In addition, dynamic sectorization, multi-sector planner and 4D trajectories were identified as new TFM concepts that will need to be assessed in the near future; these are likely to be followed by a need to investigate open-loop TFM-4D, implementation of Network Operations Plan (NOP), and the interactions of multiple components of future concepts.

Assess whether existing models can be extended to address these future concepts

Currently, the capabilities to realistically model the aforementioned future TFM concepts do not exist. In addition, many of the surveyed models have already planned implementation of improvements to existing capabilities within the next year; however, most plans did not address the future TFM concepts identified as the most critical. One could imply that the tools are not extendable to handle these concepts because of existing logic, embedded behaviors, or rigid structure programming. However, some responses indicated that improvements in the model infrastructure might facilitate the development of capabilities that allow the assessment of future concepts.

The responses revealed that the two most significant reasons behind the current inability to use the existing tools for investigation of the future TFM concepts are: (1) disconnect between the human performance and system performance models, and (2) subjective sector capacity restrictions.

System performance is affected by the timeliness and accuracy of the human performance, and cannot be accurately captured through capacity limitations alone, especially not when these are founded on subjective assessments. This area deserves considerable attention and has to be investigated and the corresponding capabilities developed and implemented in such a way to support ability to model the reallocation of roles and responsibilities between the ATC service providers, as well as between the air and ground. Also, sector capacity needs to be developed as a function of the complexity of traffic flows through the observed sector, and it needs to allow for dynamical adjustments during severe weather and traffic developments. Research to develop alerting algorithms, such as Dynamic Density Measures, could be used in fast-time simulation as a workload or capacity indicator if successfully developed. More broadly, research that addresses the need for more objective measures of sector capacity would be useful to many modeling efforts.

Responses also revealed that fidelity and capabilities of some models could be significantly improved by linking them to other models; however, this is not always easy or even possible due to different operating systems or other technical requirements for using these tools. Most of the practitioners' agree that a more open, modular, flexible architecture, such as HLA, component-based and agent-based architectures are needed to evaluate TFM and future TFM concepts. Future AP9 activities coming from this TIM (such as surveys and papers) will address all these issues.

Recommendations

In addition to the capabilities supporting modeling the future TFM concepts listed above, the following critical areas of improvements in TFM modeling capabilities have been identified:

- sector capacity as a function of the complexity of traffic flows through, and the operating conditions within, the observed sector,
- more realistic severe weather movement and impact,
- uncertainty in flights' 4D positions and their ability to meet expected times of arrival to a waypoint/airport, and more realistic modeling of a non-compliance with a traffic management initiative,
- connectivity between the human performance and the system performance models through an integration of human and system performance capabilities.

7 Abbreviations

ACC	Area Control Center
ACES	Airspace Concepts Evaluation System
ADS-B	Automatic Dependent Surveillance – Broadcast
AIP	Aeronautical Information Publication
ANM	ATFCM Notification Message
ANS	Air Navigation Service
ANSP	ANS Provider
AO	Aircraft Operators
AOC	Airline Operations Center
AOLO	Aircraft Operator Liaison Officer
AP5	Action Plan 5
AP9	Action Plan 9
ARO	Airport Reservation Office
ARTCC	Air Route Traffic Control Center
ASM	Airspace Management
ASP	Arrival Sequencing Program
AT	Air Traffic
ATA	Air Transport Association
ATC	Air Traffic Control
ATCS	Air Traffic Control System
ATCSCC	Air Traffic Control System Command Center
ATFCM	Air Traffic Flow and Capacity Management
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATS	Air Traffic Services
BADA	Base of Aircraft Data
CASA	Computer Assisted Slot Allocation
CATMT	Collaborative Air Traffic Management Technologies
CCFP	Collaborative Convective Forecast Product
CDM	Collaborative Decision Making
CDR	Coded Departure Routes

CENA	Centre d'Études de la Navigation Aérienne
CFMU	Central Flow Management Unit
CPDL	Controller Pilot Data Link
CTAS-TMA	Center TRACON Automation System Traffic Management Advisor
CTOT	Calculated Take-off Time
CWIS	Corridor Integrated Weather Diagnostic
DCA	Ronald Regan Washington National
DFS	Deutsche Flugsicherung GmbH
DP	Departure Procedures
DSP	Departure Spacing Program
ECAC	European Civil Aviation Conference
ECMWF	European Centre for Medium-range Weather Forecasts
ESP	En Route Spacing Program
ETA	Estimated Time of Arrival
ETFMS	Enhanced Tactical Flow Management System
ETMS	Enhanced Traffic Management System
EWR	Newark International Airport
FAA	Federal Aviation Administration
FMP	Flow Management Position
FMS	Flight Management System
FPL	Filed Flight Plan
FPM	Flight Plan Message
FPM DIST	Flight Plan Message Distribution Area
GDP	Ground Delay Program
GS	Ground Stop
HDTA	High Density Traffic Airports
HLA	High Level Architecture
IFPS	Integrated Initial Flight Plan Processing System
JFK	John F. Kennedy International
LAADR	Low Altitude Arrival/Departure Routing
LADP	Local Airport De-icing Plans
LGA	La Guardia International Airport

MA	Monitor Alert
MAP	Monitor Alert Parameter
MINIT	Minutes-In-Trail
MIT	Miles-In-Trail
MM5	Pacific Northwest Meso-scale Model
MSP	Multi Sector Planning
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NBAA	National Business Aviation Administration
NCAR	National Center for Atmospheric Research
NCWD	National Convective Weather Diagnostic
NCWF	National Convective Weather Forecast Product
NEXRAD	Next-Generation Radar
NGATS	Next Generation Air Transportation System
NLR	National Aerospace Laboratory
NM	Nautical Mile
NOP	Network Operations Plan
NOTAM	Notice to Airman
NRP	North American Route Program
NWS	National Weather Service
OCVSD	Operational Concept Validation Strategy Document
OEP	Operational Evolution Plan airports
ORD	Chicago O'Hare International Airport
OS	Operations Supervisor
R&D	Research and Development
RAA	Regional Airline Association
RAD	The Route Availability Document
RBS	Ration by Schedule
RCA	Remote Client Application
REA	Ready Message
RNAV	Area Navigation
RNP	Required Navigational Performance

RPL	Repetitive Flight Plan
RUC	Rapid Update Cycle
RVR	Runway Visual Range
SA	Slot Allocation
SAL	Slot Allocation List
SAM	Slot Allocation Message
SID	Standard Instrument Departure
SIT	Slot Issue Time
SRM	Slot Revision Message
STMP	Special Traffic Management Program
STA	Scheduled Times of Arrival
STAR	Standard Terminal Arrival Routes
SUA	Special Use Airspace
SWAP	Severe Weather Avoidance Plans
SWIM	System Wide Information Management
TAF	Terminal Area Forecast
TDSA	Tactical Departure Slot Allocation
TFM	Traffic Flow Management
TFM-M	Traffic Flow Management Modernization
TIM	Technical Interchange Meeting
TMA	Traffic Management Advisor
TMA	Terminal Control Area
TMC	Traffic Management Coordinators
TMI	Traffic Management Initiatives
TMS	Traffic Management Specialists
TMU	Traffic Management Unit
TOT	Take-off Time
TRACON	Terminal Radar Approach Control Facility
TRP	True Revision Process
WARP	Weather and Radar Processing
Wx	Weather

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9 APPENDIX A – TFM Survey

Traffic Flow Management Survey

Traffic Flow Management Notes for Survey

Traffic Flow Management (TFM) provides strategic planning and management to ensure a smooth and efficient flow of traffic through a relevant airspace. Traffic Management Specialists (TMS) and Traffic Management Coordinators (TMC) use collaborative decision making (CDM), automation and procedures to manage the flow of traffic in the NAS. Fast-time models (tools) have been developed to simulate many Air Traffic Control (ATC) functionalities including TFM.

The following survey is being conducted under the auspices of the FAA/Eurocontrol Research and Development Committee (specifically Action Plan 9). The goal of this survey is to determine the state of TFM simulation in fast-time modeling. Completing the attached survey will assist in our effort to identify TFM functions and initiatives covered by the existing tools, as well as future TFM concepts that might be considered for fast-time modeling. Your recognized expertise makes your time and participation critical to the mission.

For the purpose of this survey, a tool is defined as an analytical and/or simulation model. Please review the form and answer the questions that apply to the tool with which you work. And, if you use/develop multiple TFM tools, please complete a separate survey for each of the tools.

The end of the survey contains open-ended questions that invite you to identify additional functionalities of your tool that may not be included in the survey but would facilitate modeling of the current or future TFM concepts and initiatives. If you need additional space, please send your comments to **Albert Schwartz**, **Manuel Dorado** or **Almira Williams** at the contact information provided below.

On behalf of the Action Plan 9 Team, we thank you for your participation and time.

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Abbreviations Contact

Traffic Flow Management Survey

Questions marked with a * are required.

Section 1. General Characteristics of Your Tool

*1. What is the name of your tool?

*2. What type of model best describes your tool?

- [x] Discrete event simulation model
- [ ] Continuous simulation model (time-based)
- [ ] Agent based simulation model
- [ ] Analytical model
- [ ] Other, please describe

*3. What is the primary purpose of your tool and what high level objectives can it assess (i.e. capacity, safety, economics, etc.)?

4. Which platform is required for using your tool (PC/WS)?

5. Which operating system is required for using your tool?

6. Are there any other (technical) requirements for using your tool?

- ○ N/A
- ○ Other, please describe

***7.** How long does it take to prepare a simulation (min/average/max; please specify unit)?

***8.** How long does it take to run a simulation (min/average/max; please specify unit)?

***9.** How long does it take to generate the outputs (min/average/max; please specify unit)?

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Questions marked with a * are required.

Section 2. Planning and Coordination

***10.** Can your tool be used to model the long-term TFM research, planning and coordination actions that take place seven days or more prior to the day of operation? If so, please describe.

- N/A
- Other, please describe

***11.** Can your tool be used to model the medium-term TFM planning and coordination actions that take place up to six days prior to the day of operation? If so, please describe.

- N/A
- Other, please describe

***12.** Can your tool be used to model the short-term TFM planning and coordination activities that take place on the day of the operation? If so, please describe.

- N/A
- Other, please describe

***13.** Can your tool be used to model the potential TFM activities that take place shortly before a flight's scheduled or actual departure (in US, up to two hours before scheduled departure and while airborne, and in Europe, up to 45 minutes before sector entry and while airborne)? If so, please describe.

- ○ N/A
- ○ Other, please describe

***14.** Can your tool be used to model the Air Traffic Control activities that monitor and separate a flight while airborne from all other nearby flights? If so, please describe.

- ○ N/A
- ○ Other, please describe

***15.** Can your tool be used to model the post-ops analytical activities that scrutinize the operations to understand how well TFM initiatives were executed and how effective they were? If yes, please describe.

- ○ N/A
- ○ Other, please describe

Does your tool model flight re-planning process? If so, the following five (5) questions are related to your tool's planning capabilities.

***16.** Can flight trajectory be amended as a result of the re-planning process?

- ○ N/A
- ○ Other, please describe

*17. Can flight departure time be amended as a result of the re-planning process?

- N/A
- Other, please describe

*18. Can a flight be cancelled as a result of the re-planning process?

- N/A
- Other, please describe

*19. Can flights swap trajectories as a part of the re-planning process (for instance, a more important flight obtains better trajectory)?

- N/A
- Other, please describe

*20. Can your tool model other re-planning functions/actions not covered above?

- N/A
- Other, please describe

The following three(3) questions are related to your tool's in-flight decision making capabilities.

***21.** What is the look-ahead horizon for the in-flight decision making? Is this a user defined input?

- ◯ N/A
- ◯ Other, please describe

***22.** How does in-flight decision making affect other flights and TFM initiatives in your tool?

- ◯ N/A
- ◯ Other, please describe

***23.** Can your tool model other in-flight decision making functions/actions not covered above?

- ◯ N/A
- ◯ Other, please describe

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Questions marked with a * are required.

Section 3. Inputs and Logic

***24.** Are flight schedules one of the required inputs? If yes, what type of schedules can be used?

- [x] N/A
- [ ] OAG schedules
- [ ] Other, please describe

***25.** Are flight plans one of the required inputs? If so, what fields are included in the flight plan?

- [x] N/A
- [ ] Departure time
- [ ] Arrival time
- [ ] Route
- [ ] Aircraft type
- [ ] Flight level requested
- [ ] Departure airport
- [ ] Arrival airport
- [ ] Equipage (RNP, ADS, etc.)
- [ ] Other, please describe

***26.** Are the initial flight trajectories obtained or modeled as one of the following? Please select all that apply.

- [x] N/A
- [ ] Flight plan filed route for each of the flights
- [ ] Great circle routes
- [ ] Wind optimized great circle routes
- [ ] Other, please describe

***27.** Does your tool consider uncertainty in flights 4D positions? If so, is the uncertainty modeled differently for horizontal, vertical and time dimensions?
Please list the factors used to determine uncertainty.

- [x] N/A
- [ ] Other, please describe

***28.** Does your tool model non-compliance with a TFM Initiative? If yes, please explain the actions the tool takes in the case of non-compliance. (Note: non-compliance with a TMI translates into airplanes not being where and when they are expected.)

- [x] N/A
- [ ] Other, please describe

***29.** Does your tool consider cost efficiencies of the possible TFM measures (delay if GDP, delay or extra mileage if rerouting, etc.)?

- [x] N/A
- [ ] Overflight user fees
- [ ] Capacity unit costs
- [ ] Delay unit costs
- [ ] Other, please describe

*30. Does your tool model flight cancellations? If yes, how does it determine when to cancel a flight?

○ N/A
○ Other, please describe

*31. Does your tool model diversions to other airports? If yes, does it also allow for the recovery back to its original airport?

○ N/A
○ Other, please describe

*32. Does your tool allow for flight or slot swaps? If yes, how does it determine when and which aircraft?

○ N/A
○ Other, please describe

*33. Does your tool model Miles and/or Minutes in trail restrictions? If so, please select the criteria specific to implementing Miles and Minutes in trail restrictions:

- 1, if n/a
- 2, if Separation (aircraft to aircraft)
- 3, if Airport: Origin
- 4, if Airport: Destination
- 5, if Fix
- 6, if Altitude
- 7, if Sector
- 8, if Route
- 9, if Other

	1	2	3	4	5	6	7	8	9
Miles in Trail	☐	☑	☑	☑	☐	☐	☐	☐	☐
Minutes in Trail	☑	☐	☐	☐	☑	☑	☑	☑	☑

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Questions marked with a * are required.

The following four questions relate to your tool's metering or sequencing abilities (maintaining a specific sequence of aircraft, including the order and desired spacing between flights

*34. Can your tool model arrival sequencing? Please select all that apply.

- [x] N/A
- [ ] By outer fix
- [ ] By runway
- [ ] By meter fix
- [ ] By meter arc (similar to TMA)
- [ ] Other, please describe

*35. Can your tool model departure sequencing (for multiple or single airport)? Please select all that apply.

- [x] N/A
- [ ] To a fix
- [ ] To a route
- [ ] Other, please describe

*36. Can your tool model en route sequencing?

- [x] N/A
- [ ] By adjusting departure time to facilitate en route sequencing
- [ ] Other, please describe

*37. Is the sequencing interval user specified?

- [x] N/A
- [ ] Other, please describe

*38. Does your tool model Collaborative Decision Making? If yes, how is it processed?

- [x] N/A
- [ ] The tool models message exchange – information is passed from one actor to another without an effect on the system
- [ ] The tool models system interaction – information is passed between the actors that modify the system in some way
- [ ] The tool models agents – actors are individual software agents that contain known behaviors which may affect the system
- [ ] Other, please describe

*39. Does your tool model the communications between the following actors? Please select all that apply.

- [x] N/A
- [ ] Pilot and Controller
- [ ] Controller and Traffic Manager
- [ ] Traffic Manager and Dispatcher/AOC
- [ ] Dispatcher/AOC and Pilot
- [ ] Other, please describe

*40. Does your tool model actions and workload of the following actors? For each of the actors, please select:

- 1, if n/a
- 2, if the actor’s actions are modeled
- 3, if the actor’s workload is modeled

	1	2	3
R side controller	☑	☐	☐
D side controller	☐	☑	☐
Combined R&D side controllers	☐	☑	☐
Pilots	☐	☐	☑
Local Traffic Manager	☐	☑	☐
Global/network traffic manager	☐	☑	☐
Dispatcher or AOC	☐	☑	☑

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***41.** Does your tool model aircraft performance characteristics? If yes, what are they based on?

- [x] N/A
- [ ] Lookup tables
- [ ] Equations
- [ ] Other, please describe

***42.** How many different aircraft classifications can your tool model? Please select all that apply.

- [x] Wake turbulence (Heavy, Large, Small ...)
- [ ] ICAO performance groups (A, B, C ...)
- [ ] Engine types (turboprop, jet ...)
- [ ] Noise chapter classification
- [ ] Individual aircraft models
- [ ] Other, please describe

***43.** Does your tool determine aircraft speeds by considering the following? Please select all that apply.

- [x] N/A
- [ ] Phase of flight
- [ ] Range of climb/descent rates
- [ ] Range acceleration/deceleration rates
- [ ] Altitude
- [ ] ISO atmosphere
- [ ] Winds
- [ ] Other, please describe

***44.** Does your tool determine fuel burn by considering the following? Please select all that apply.

- [x] N/A
- [ ] Aircraft speed
- [ ] Altitude
- [ ] Wind
- [ ] Other, please describe

***45.** Are there any other aircraft performance related capabilities about your tool you would like to emphasize?

- ( ) N/A
- ( ) Other, please describe

***46.** Does your tool model aircraft to aircraft separation standards? Please select all that apply.

- [x] N/A
- [ ] Longitudinal separations between individual flights
- [ ] Lateral separations between individual flights
- [ ] Vertical separations between individual flights

***47.** Does your tool implement separation standards as a function of domain? Please select all that apply.

- [x] N/A
- [ ] Oceanic en route
- [ ] Domestic en route
- [ ] Terminal
- [ ] Airport

***48.** Does your tool implement separation standards as a function of phase of flight? Please select all that apply.

- [x] N/A
- [ ] Takeoff
- [ ] Departure
- [ ] Cruise
- [ ] Descent
- [ ] Final approach
- [ ] Landing

***49.** Does your tool distinguish and implement separation standards as a function of aircraft equipage (RNP, CPDL, ADS-B, ADS-C, etc.)?

○ n/a
○ Other, please describe

***50.** Does your tool use specific rerouting options to respond to weather or to alleviate traffic congestion? If yes, how is this performed? Please select all that apply.

- 1, if n/a
- 2, if the tool implements the options specified by the input parameters by individual flights
- 3, if the tool implements the options specified by the input parameters by a given category of flights (deps from a specified airport, arrs to a specified airport, specified type of flights such as scheduled, cargo, GA, etc.)
- 4, if the tool chooses the most appropriate options based on the forecasted traffic situation and implements these options before take-off
- 5, if the tool chooses the most appropriate options based on the forecasted traffic situation and implements these options in-flight
- 6, if the tool chooses the most appropriate options based on the forecasted traffic and weather situation and implements these options before take-off
- 7, if the tool chooses the most appropriate options based on the forecasted traffic and weather situation and implements these options in-flight

	1	2	3	4	5	6	7
Reroutes to remain clear of Special Use Airspace, congested airspace, or weather	☑	☐	☐	☐	☐	☐	☐
Low altitude arrival/departure routing (LAADR) (segregating unidirectional stream aircraft by keeping it lower than their requested route)	☑	☐	☐	☐	☐	☐	☐
Capping (holding aircraft at lower altitudes until they are clear of a particular area)	☑	☐	☐	☐	☐	☐	☐
Tunneling (descending traffic prior to the normal descent point at an arrival airport to remain clear of an airspace situation on the route of flight)	☑	☐	☐	☐	☐	☐	☐
National Playbook Routes or European re-routing scenarios, and response schemes (contingency measures)	☑	☐	☐	☐	☐	☐	☐
ATC Preferred Routes (published by ATC to inform users of the ATC Preferred traffic flows between airports)	☑	☐	☐	☐	☐	☐	☐
Coded Departure Routes (a combination of coded air traffic routings and refined coordination procedures)	☑	☐	☐	☐	☐	☐	☐
Conditional Routes of which usage can be planned at certain look ahead horizon depending on military activity	☑	☐	☐	☐	☐	☐	☐
Standard Instrument Departures (SID)	☑	☐	☐	☐	☐	☐	☐
Standard Terminal Arrival Routes (STAR)	☑	☐	☐	☐	☐	☐	☐
Required Navigation Performance (RNP) Area Navigation (RNAV)	☑	☐	☐	☐	☐	☐	☐
Oceanic Routing: Flexible tracks	☑	☐	☐	☐	☐	☐	☐
Oceanic Routing: Fixed Tracks	☑	☐	☐	☐	☐	☐	☐
Oceanic Routing: User Preferred Tracks	☑	☐	☐	☐	☐	☐	☐

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Questions marked with a * are required.

*51. Are there any additional rerouting options, strategies, initiatives, or simply logic that your tool implements but were not included in the previous question? If yes, please describe them here.

- N/A
- Other, please describe

***52.** Can your tool model aircraft holding? If yes, how is the need for holding determined? Does your tool perform this function dynamically or based on user defined input? Where can holding take place: terminal, en-route; both? Is the holding pattern defined? Can users specify various holding techniques (first in-first out, first in-multiple out, etc.)?

○ N/A

○ Other, please describe

***53.** Does your model consider airspace sectors? Please select all that apply.

☑ N/A

☐ Considers the shape and the geographic location of each of the sectors

☐ Consider the altitude band for each of the sectors

☐ Other, please describe

***54.** Does your tool consider sector capacity? Please select all that apply.

- [x] N/A
- [ ] Individual sector capacity is hard-coded
- [ ] Individual sector capacity is user specified and cannot be changed during a run
- [ ] Individual sector capacity is user specified and can be changed at pre-specified times during a single run
- [ ] Sector capacity is determined by considering the route structure within the sector (geometry of the available routes and the applicable separation standards)
- [ ] Sector capacity is determined by considering traffic situation within the sector (geometry of the flown trajectories and the applicable separation standards)
- [ ] Sector capacity is determined by considering traffic and weather situations within the sector
- [ ] Other, please describe

***55.** Does your tool evaluate sector demand against sector capacity? If so, what actions does it take when demand exceeds capacity?

- ○ n/a
- ○ Other, please describe

***56.** Does your tool implement Monitor Alert Parameter (MAP) values? Please select all that apply.

- [x] N/A
- [ ] MAP values are implemented as equivalent to sector capacity
- [ ] MAP values cannot change during a run
- [ ] MAP values can automatically be adjusted to respond to weather and/or traffic development?
- [ ] Other, please describe

***57.** How does your tool react to exceeding the MAP values (Re-routes around congested sectors, Holding-where, etc.)?

- ○ N/A
- ○ Other, please describe

***58.** Does your tool consider Special Use Airspace? Please select all that apply.

- [x] N/A
- [ ] Considers the shape and the geographic location of Special Use Airspace
- [ ] Considers the altitude band reserved for Special Use Airspace
- [ ] Other, please describe

*59. Can the characteristics of a Special Use Airspace change during a run (for instance, on/off status, etc.)?

○ N/A

○ Other, please describe

*60. Does your tool implement TFM initiatives based on geographic boundaries of the managed airspace; for instance, air route traffic control center (ARTCC) based geographic tiers in the U.S. or the TFM Area in Europe?

- [x] N/A
- [ ] The tool applies TFM measures to all flights departing from an airport within the specified area
- [ ] The tool applies TFM measures to all flights transiting a specified area or route
- [ ] The tool applies TFM measures to all flights landing at an airport within the specified area
- [ ] The tool applies TFM measures to some flights departing from an airport within the specified area
- [ ] The tool applies TFM measures to some flights transiting a specified area or route
- [ ] The tool applies TFM measures to some flights landing at an airport within the specified area
- [ ] Other, please describe

***61.** Does your tool model severe weather cells?

- [x] N/A
- [ ] It considers reduced resource capacity as dictated by severe weather, but does not model Wx cells specifically
- [ ] It models severe weather cell location and shape
- [ ] It models moving weather cells
- [ ] It models time period during which weather cell is active
- [ ] Other, please describe

***62.** What source of weather data does your tool use to model severe weather cells?

- ○ N/A
- ○ Other, please describe

***63.** How does your tool respond to severe weather cells affecting the traffic operations?

- [x] N/A
- [ ] It creates re-routes around the weather,
- [ ] It adjusts MAP values for the affected sectors,
- [ ] It introduces miles in trail restrictions in appropriate areas/routes,
- [ ] It introduces minutes in trail restrictions in appropriate areas/routes,
- [ ] It introduces GDP at the appropriate airports,
- [ ] It introduces GS at the appropriate airports,
- [ ] It models Severe Weather Avoidance Plans (SWAP)
- [ ] Other, please describe

***64.** Does your tool model Local Airport De-icing Plans (local strategies for minimizing the amount of time an aircraft spends on the ground after being deiced/anti-iced)?

- ○ N/A
- ○ Other, please describe

*65. Does your tool model airports?

- [x] N/A
- [ ] Airports are modeled as sink/source points with no queuing
- [ ] Airports are modeled as queues with arrival and departure capacities
- [ ] Only runways are modeled and arrival/departure separations applied
- [ ] Airports are modeled as a system of runway(s), taxiway(s) and gates
- [ ] Other, please describe

*66. How does your tool determine airport capacity?

- [x] Airport capacity is not considered (N/A)
- [ ] The tool distinguishes between departure and arrival airport capacity
- [ ] Airport capacity is specified as an input parameter for the whole airport
- [ ] Airport capacity is specified as an input parameter for the individual runways
- [ ] Airport throughput is determined by processing flights and through application of separation standards
- [ ] Other, please describe

***67.** How many airports can your tool model? Are all of the airports modeled to the same level of detail? Please describe.

- ○ N/A
- ○ Other, please describe

***68.** Does your tool evaluate airport demand against airport capacity? If so, what actions does it take when demand exceeds capacity?

- ○ n/a
- ○ Other, please describe

***69.** Does your tool model Ground Delay Programs (GDP) or Slot Allocation (SA)? If so, what events trigger GDP or SA?

- [x] N/A
- [ ] Weather en route
- [ ] Weather at (destination) airport
- [ ] Other, please describe

***70.** Does your tool model Ground Stops (GS) or Tactical Departure Slot Allocation (TDSA)? If so, what events trigger GS or TDSA?

- [x] N/A
- [ ] Reduced capacity due to weather below user arrival minima
- [ ] Reduced capacity due to severe weather on routes
- [ ] Reduced capacity due to major equipment outages
- [ ] Reduced capacity due to catastrophic events
- [ ] Precluding extended periods of airborne holding
- [ ] Precluding sectors from reaching saturation levels
- [ ] Precluding airports from reaching gridlock
- [ ] Other, please describe

***71.** Does your tool model Fix Balancing (assigning an aircraft a fix other than the fix specified in the filed flight plan for the arrival or departure phase of flight with a goal of equitably distributing demand)? If yes, please describe (how is it performed? is it dynamic? are the fix balancing parameters user defined?)

- ○ N/A
- ○ Other, please describe

*72. Does your tool implement any of the following TFM restrictions? For each of the restrictions, please select all that apply:

- 1, if n/a
- 2, if the characteristics of the restriction are hard-coded
- 3, if the characteristics of the restriction are user-specified
- 4, if the characteristics of the restriction can be different for different resources
- 5, if the characteristics of the restriction can change during a run
- 6, if the restriction is automatically triggered by the tool according to traffic development
- 7, if the restriction is automatically triggered by the tool according to weather development

	1	2	3	4	5	6	7
Miles in Trail	☑	☐	☐	☐	☐	☐	☐
Minutes in Trail	☑	☐	☐	☐	☐	☐	☐
MAP values	☑	☐	☐	☐	☐	☐	☐
GDP	☑	☐	☐	☐	☐	☐	☐
GS	☑	☐	☐	☐	☐	☐	☐
Airport slot control	☑	☐	☐	☐	☐	☐	☐

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*73. Does your tool support Dynamic Sectorization? If yes, how is Dynamic Sectorization accomplished (through dynamic construction of new sectors, i.e. new sector boundaries, or through reconfiguration of the predefined, static, sectors, i.e., sector merging and splitting)

- N/A
- Other, please describe

*74. Does your tool model 4D contracts?

- N/A
- Other, please describe

The following eight (8) questions are all related to Multi Sector Planning (MSP).

*75. Does your tool model Multi Sector Planning? If so, what method does it use?

- n/a
- MSP is modeled as a Multi-D controller supporting several R-side controllers
- MSP is modeled as a local TFM controller or as a part of the global/network TFM team responsible for redistributing traffic flows across several controlled sectors with a goal of assisting the corresponding controllers.
- Other, please describe

*76. If MSP is being modeled as a Multi-D controller , how many R-side controllers can a single Multi-D side support?

- ○ n/a
- ○ Other, please describe

*77. If MSP is being modeled as a Multi-D controller, what tasks is a Multi-D controller resposible for?

- ☑ n/a
- ☐ Hand-Offs
- ☐ Coordination with adjacent sectors
- ☐ Re-routing /FL capping/spacing/sequencing within all of the controlled sectors
- ☐ Other, please describe

*78. If MSP is being modeled as a Multi-D controller, can your tool support coordination between two or more Multi-D controllers?

- ○ n/a
- ○ Other, please describe

*79. If MSP is being modeled as a local TFM controller, how many sectors can be supported by a single MSP?

- ○ N/A
- ○ Other, please describe

***80.** If MSP is being modeled as a local TFM controller, does your tool model seperately the R-side and D-side controllers for the controlled sectors (in addition to MSP)? If yes, please describe the tasks performed by the controllers.

- ○ n/a
- ○ Other, please describe

***81.** If MSP is being modeled as a local TFM controller, what tasks is MSP responsible for?

- ☑ n/a
- ☐ Hand-offs
- ☐ Coordination with adjacent sectors
- ☐ Re-routing/FL capping/spacing/sequencing within the controlled sectors
- ☐ Other, please describe

***82.** If MSP is being modeled as a local TFM controller, can your tool support coordination between two or more MSP?

- ○ n/a
- ○ Other, please describe

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Questions marked with a * are required.

Section 4. Outputs

83. What outputs does your tool produce? (Select all that apply)

- [ ]
- [ ] Simulation log
- [ ] Reports: Various statistics by individual flights
- [ ] Reports: Various statistics by individual sectors
- [ ] Reports: Various statistics by individual airports
- [ ] Reports: Various statistics by individual other resources (fixes, routes, etc)
- [ ] Reports: Averages, variances, etc.

***84.** What metrics does your tool calculate?

- [ ]
- [ ] Capacity
- [ ] Delay
- [ ] Predictability
- [ ] Flexibility
- [ ] Safety
- [ ] Flight efficiency
- [ ] Environment
- [ ] Complexity

*85. Does your tool produce graphics/maps?

*86. Does your tool provide animation capabilities?

*87. Please describe briefly the types of studies that the tool was used for.

*88. What major improvements would you like to implement in your tool?

*89. Are any of these improvements planned for near/mid term future (within 1 year)?

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10 APPENDIX B – Model Description and Reference

This appendix provides a brief description of the surveyed tools as responded by the point of contact. Content has not been modified; formatting has been changed for readability.

Name: ABNA (Airspace BottleNeck Analyzer)

Type of Model: Queue-process macroscopic model. The tool model airspace and airports as a network, where nodes are sectors and airports with a specified capacity and flights are individual items using capacity nodes during a given time specified in their plans.

Primary Purpose: Analyze bottlenecks in wide airspace and airports networks:

High level objectives are:

- Overall capacity (e.g. Control Center Capacity, region capacity...)

- Economics: delay comparison, number of delayed flights comparison.

Platform: PC

Operating System: Windows

Metrics: Capacity; Delayed flights; Delay

Types of Studies: Network analysis of local changes. Impact on overall capacity and delay due to local changes in capacity (split sectors, new configurations, new capacity restrictions...)

Name: Airspace Concepts Evaluation System (ACES)

Type of Model: Agent based simulation model

Primary Purpose: The primary purpose of ACES is to perform system-wide benefit assessments of air traffic management technologies and concepts. In addition, ACES predicts delay vs. different demand and capacity scenarios.

ACES possesses the ability to calculate many different metrics. Ones that have been generated so far are arrival & departure rates at specified points in the airspace or at an airport; sector & center flight counts; number, duration, and location of flight deviations and conflicts; and number of hand-offs, cancellations, and monitor alerts. ACES also links with NIRS, EDMS, CNS models, and Air MITAS. These models can be used to calculate noise, emissions, CNS, and controller workload metrics.

Platform: ACES runs on PC or WS.

Operating System: ACES runs on LINUX, Windows, and OSX.

Metrics: Delay; Environment; Flight efficiency; Safety

Types of Studies: ACES has been used to 1) study an automated conflict resolution and detection technology, 2) assess the impacts of VAMS air traffic management concepts, and 3) predict future delays vs. various future demand and capacity scenarios.

Name: AEM3 - Advanced Emission Model (version 3)

Type of Model: Analytical model

Primary Purpose: Estimation of Aviation Emissions to assess environmental impact of aviation (ATC/ATM etc.) scenarios

Platform: PC

Operating System: Windows

Metrics: Environment; Global Aviation emissions (1 - several ten thousand flights) based on individual flight profiles

Types of Studies: EUR-RVSM, MFF, MFF2, Cost of Delay, CEATS implementation, Aviation & Fuel Cells, SOURDINEII, FAA/EUROCONTROL ICAO/CAEP study (2000) and will be used for JPDO,SESAR, EPISODE3

Name: ATC-HPM (Air Traffic Control - Human Performance Model) using the Micro Saint Sharp discrete event simulation integrated with CSSI's 4-D trajectory and airspace model

Type of Model: Discrete event simulation model

Primary Purpose: Predicting controller workload and the impact of the controller's workload on en route sector capacity

Platform: PC

Operating System: Windows XP

Metrics: Capacity

Types of Studies: Assessing controller workload for advanced concepts such as distributed air ground traffic management and CPDLC.

Name: Attila Simulator

Type of Model: Agent based simulation model; discrete event simulation model; discrete events generated for each trajectory. Object agents representing each managed flight.

Primary Purpose: The primary purpose is to evaluate economic and capacity impact of various arrival schemes at an airport. The system models various goals set by the user, such as fuel optimization, schedule conformance, or load factor for example. It then measures the effects of such an optimization in time and economic terms. The system allows for various airport conditions, pilot compliance rates and the amount of traffic that is manageable.

Platform: PC or WS

Operating System: Any operating system supporting a standard C++ compiler

Metrics: Capacity; Delay; Environment; Flight efficiency

Types of Studies: The tool has been used to measure the economic effects of various optimization schemes on several airports for airline operators. These included the ongoing work in Atlanta, with ATH Group and Delta airlines, as well as analysis of the Denver and Charlotte airports.

Name: AwSim

Type of Model: Agent based simulation model; discrete event simulation model; discrete events generated for individual Trajectory object agents (each representing a flight)

Primary Purpose: The top level objective is to measure the effects of changes in the airspace as a whole. This can include changes to policies, equipment, fleet mix, or demographics for example.

Platform: PC or WS.

Operating System: Any OS supporting a standard C++ compiler.

Metrics: A set of about 40 metrics by flight, by airspace, by airport, or by fix.; Capacity; Complexity; Delay; Flight efficiency

Types of Studies:

(1) Source of Trajectory data and metrics tool for a study of controllers' responses (FAATC HFL), with live controllers ""plugged in"" as one of the system modules;

(2) Effects of fleet composition changes on traffic patterns and density (NASA/Langley), with macro-economic simulation results used as input into AwSim;

(3) Analysis of traffic patterns and various weather avoidance strategies (FAA TC) with resulte of NASPAC simulation fed as atarting poin for AwSim;

(4) Analysis of various policy effects on traffic metrics (FAA Code 400)

(5) Dynamic Traffic Flow Simulation, with AwSim interfaced directly to TMA.

(6) Ground delay program under delivery analysis.

(7) Excess distance analysis for FAA freeflight program.

(8) Airport/Airline optimization analysis for ATH Group and Delta airlines at Atlanta airport, supporting the operation Attila system.

Name: CAASD's system wide modeler

Type of Model: Discrete event simulation model

Primary Purpose: To estimate delay and load in various elements of the NAS under scenarios that differ (1) by traffic volumes, schedules, routes, equipment, and equipage, (2) airport, TRACON, and sector capacities, (3) traffic management initiatives.

Platform: PC

Operating System: Windows

Metrics: None. We log and let analysts post-process.

Types of Studies: OEP benefits, CPDLC benefits, AFP analysis, HAR redesign load analysis

Name: COSAAC/SHAMAN

Type of Model: Analytical model

Primary Purpose: Traffic flow analysis and traffic modifications (increase, rerouting, slot allocation, ...)

High level objective: capacity

Platform: PC

Operating System: Linux

Metrics: Delay

Types of Studies: Resectorizations, Rerouting plans

Name: Future ATM Concept Evaluation Tool (FACET)

Type of Model: Continuous simulation model (time-based)

Primary Purpose: The Future ATM Concepts Evaluation Tool (FACET) is a flexible Air Traffic Management (ATM) simulation environment that has been established for exploring, developing, and evaluating advanced ATM concepts. The primary objective that the system can access is capacity and to a lesser extent economics (delays).

Platform: FACET has been operated on Solaris workstations, PCs, and Macintosh computers.

Operating System: FACET can be run under multiple operating systems, such as Solaris, Linux, and Mac OS X.

Metrics: Complexity; Delay; Demand

Types of Studies: Roughly 30 peer reviewed journal and conference papers have been published using FACET. Areas of study include: airborne self separation, air and space vehicle integration, TFM initiative modeling, wind optimal routing, aggregate flow modeling, dynamic resectorization, etc.

Name: Jupiter Simulation Environment (JSE)

Type of Model: Agent based simulation model; Continuous simulation model (time-based); discrete event simulation model

Primary Purpose: JSE is a real-time and fast-time simulator that is focused on showing capacity and demand imbalances. The primary purpose of the tool is two-fold: as a human-in-the-loop simulator for validating new operational concepts and a fast-time simulator to show impacts to the NAS for concept evaluation and analysis.

Platform: Depending on the topology and desired scope of the simulation, JSE can be run on a laptop to a server farm. The laptop capability is generally used for demonstrations while full human-in-the-loop exercises are conducted in a multiple server configuration.

Operating System: JSE is Java built, so it is supported on the major platforms (Windows, Mac, Solaris, and Linux).

Metrics: Capacity; Complexity; Delay

Type of Studies: The following capabilities were deployed or are about to be deployed to operations through testing a concept evaluation using JSE: Airspace Flow Program, Slot Credit Substitution, Adapative Compression, and GAAP.

Name: LMINET

Type of Model: Analytical model

Primary Purpose: LMINET is primarily used to estimate delays; the capacity benefits of new technologies, policies, infrastructure, and procedures; and the amount of traffic demand that can be accommodated in a future system with a tolerable level of delay.

Platform: Unix and Windows platforms.

Operating System: Unix and Windows.

Metrics: Capacity; Delay

Types of Studies: NASA, FAA, and JPDO studies.

Name: MIT Extensible Air Network Simulation (MEANS)

Type of Model: Discrete event simulation model

Primary Purpose: The MIT Extensible Air Network Simulation (MEANS) is an event-based NAS simulation model that provides a framework for analyzing a wide array of ATM and airline strategies, including:

* Robust Scheduling

* Robust Operational Procedures

* Disruption Recovery Optimization

* Congestion Trends

* Effects of Rule Changes on Capacity

Platform: PC/Mac/Unix

Operating System: Linux, Solaris, MacOS

Metrics: Capacity; Delay; Predictability

Types of Studies:

- Investigation of schedule changes

- Investigation of optimizing strategies used by AOC
- Evaluation of flight sequencing
- Prediction of future delays

Name: MENTOR

Type of Model: Discrete event simulation model

Primary Purpose: To analyze and optimize the system in terms of the relationship between sector capacity and traffic demand.

Platform: A PC with a run time license of WITNESS(commercial software for development of general purpose simulation models).

Operating System: Microsoft Windows 2000 or XP.

Metrics: Capacity; Complexity; Delay

Types of Studies: Capacity planning, system bottlenecks, sectoring and route network optimization.

Name: NARIM

Type of Model: Analytical model

Primary Purpose: High level focus on efficiency and factors affecting airspace capacity (conflicts and density).

Platform: Either

Operating System: Unix, windows. Programs are written in C/C++ and engines are portable between platforms.

Metrics: Conflicts by geometry, sector loading.; Delay; Flight efficiency; Predictability

Types of Studies: Originally designed to investigate efficiency gains of free-flight and determine if conflicts and density would be altered significantly under those concepts.

Name: NASPAC

Type of Model: Discrete event simulation model

Primary Purpose: Simulate NAS operations to determine Capacity/Demand Imbalances

Platform: Sun Work Station (Ultra 80)

Operating System: Solarius 9.0

Last Changed on 8/28/2006

Metrics: Capacity; Delay; Flight efficiency

Types of Studies: ERAMS, DRVSM, DFW MTROPLEX, ATL Expansion SFO-LAX reroutes. Studies that involve quantifying NAS performance based on proposed changes to System capacities.

Name: National Flow Model (NFM)

Type of Model: Discrete event simulation model

Primary Purpose: The Boeing National Flow Model (NFM) is a large-scale simulation of aircraft flow in the US National Airspace (NAS) for all operations in a single day. The model is intended to be used to measure system effectiveness of current and future airport and airspace capacity levels and for current and future Air Traffic Management operational concepts. The model is designed to consider all traffic (input as tail-routed schedules) on the day of operations, considers airport arrival rate limits, airport departure rate limits, and sector occupancy limits, measures originating and propagated delays, and can model actual and forecast convective weather, and dynamic system responses including airline schedule recovery and ground delay programs. The focus is on capacity and delay analysis. The model does not directly address aircraft separation and safety issues.

The model has been used in a variety of studies including (but not limited to) airports/airspace capacity improvement benefits analysis, delay analysis, analysis of alternative and improved methods for flow management and airline schedule recovery, and benefits analysis for improved convective weather forecasting. Included is a partial list of studies that the NFM has been used for (with most conducted for both current and future traffic levels using the companion capability for future airline schedule generation capability):

* Benefits analysis for airport capacity improvement initiatives

* Benefits analysis for airspace capacity improvement initiatives (including sector bottleneck analysis and parametric capacity improvement studies)

* Benefits analysis for combined airports and airspace capacity improvement initiatives (exploring ""balanced"" solutions; to be completed by July 31, y2006)

* Benefits analysis for SWIM-enabled application for ""distributed airline schedule recovery"" which explores the benefits (in a severe convective weather scenario) of improved schedule recovery automation and, also, the benefits of improved convective weather forecasting

* Benefits analysis for improved automation methods for utilizing coded departure routes using a Houston area scenario with a convective weather disturbance

* And others (including benchmarking and calibration type studies)

Platform: PC (current version); Unix workstations (available for prior version)

Operating System: Windows 2000 or XP (current version); SunOS (prior version)

Metrics: Delay

Types of Studies: Here is a partial list of studies that the NFM has been used for (with most conducted for both current and future traffic levels using the companion capability for future airline schedule generation capability):

* Benefits analysis for airport capacity improvement initiatives

* Benefits analysis for airspace capacity improvement initiatives (including sector bottleneck analysis and parametric capacity improvement studies)

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* And others (including benchmarking and calibration type studies)

Name: OPAS (which is in fact composed of two simulators:

- OPAS-En-route for en-route operations
- OPAS-TMA for approach)

Type of Model: Continuous simulation model (time-based)

Primary Purpose: The primary purpose of OPAS is to evaluate the impact of changes in sectors/routes/procedures as well as the impact of new concepts (e.g., Free-Routes, ASAS)

Platform: PC

Operating System: Linux or Windows

Metrics: Complexity; Environment; Flight efficiency

Types of Studies: New procedures on major French airports (Roissy, Orly, Lyon, Toulouse). Studies on new concepts such as Free-Routes, RVSM as well as ASAS Crossing and Spacing.

Name: Probabilistic Automation-Assisted En Route Congestion Management Tool (PACER)

Type of Model: Continuous simulation model (time-based)

Primary Purpose: The tool models national air traffic demand and capacity using probabilistic forecasts to explicitly account for uncertainty, and proposes integrated solutions to manage forecast congestion problems. The tool provides impact assessment feedback to allow decision makers to asses the effectiveness and costs of proposed solutions. It is also used to investigate and evaluate human interaction and collaboration using this type of automated decision support.

Platform: Dual processor PC with 6 Gigabytes memory.

Operating System: Linux

Metrics: Capacity; Delay; Predictability

Types of Studies: PACER is used as a tool to estimate the benefits of proposed TFM automation and procedures, including PACER itself. The usefulness and human factors of presenting probabilistic demand and capacity information to decision makers has been studied.

Name: SIMMOD

Type of Model: Discrete event simulation model

Primary Purpose: The primary purpose is capacity and delay studies for airports and surrounding airspace.

Platform: PC, Workstation

Operating System: Windows, UNIX, LINUX

Metrics: Capacity; Delay

Types of Studies: Most of the SIMMOD studies are for TRACON areas or Airports.

Name: TAAM; TAAM: Total Airspace and Airport Modeller

Type of Model: Continuous simulation model (time-based); discrete event simulation model

Primary Purpose: Capacity and productivity analysis for airspace and airport; TAAM is used to investigate the economic impact of changes to policy, planning and operations of air traffic management. The 'economics' comprise capacity and workload, throughput and delay, activities and environmental emissions.

Platform: PC; TAAM runs on off-the-shelf laptops and desktops.

Operating System: LINUX; Solaris 9 or 10 or Redhat Enterprise Linux 3 or 4

Metrics: Capacity; Delay; The TAAM reporter enables the user to compare planned and actual flight times, events (type, time and location). From these the user can draw conclusions about delays, predictability, safety and workload, flight efficiency and environmental impact.

Types of Studies:

Airport and Airspace optimization ; TAAM is used for studies from 0.5 days to 10 years before the event.

Long term 'policy' studies have included evaluation of Functional Blocks of Airspace and the implementation of RVSM

Medium term 'planning' studies have included airspace re-architecture and capital works such as new runways.

Short term 'operations' studies have included determination of expected workload due to navigation aids disabled temporarily.

Name: TACOT

Type of Model: Continuous simulation model (time-based)

Primary Purpose: Capacity

Platform: PC or WS

Operating System: Linux or HP/Unix

Metrics: Delay; Predictability

Types of Studies: ATFCM operational studies

Name: Terminal Area Route Generation Evaluation and Traffic Simulation (TARGETS)

Type of Model: Continuous simulation model (time-based)

Primary Purpose: TARGETS is primarily for procedure design. Its simulation capability can be used to collect separation data and perform benefits analysis.

Platform: PC

Operating System: Any (Java)

Metrics: Separation

Types of Studies:

FAA Big Airspace Route Development

United Parcel Service Continuous Decent Approach Development

Converging Runway Display Aid Analysis

Benefits Analysis

Integration with the Integrated Noise Model program.

DME Coverage Analysis

TARGETS has been used to model the benefits and develop concepts for the terminal area based upon RNAV arrival and departure procedures and RNP approach procedures. The simulation has been used in fast time for parametric sensitivity analysis and in real time for simplified human-in-the-loop simulations. "

Name: TOPAZ (Traffic Organization and Perturbation AnalyZer)

Type of Models: All four types

Primary Purpose: Safety as function of capacity

Platform: Powerful PC or Workstation

Operating System: Windows

Metrics: Safety; Safety in terms of well defined accident and/or incident events, as a function of capacity related parameter values. TOPAZ also provides an estimation of the bias and uncertainty in the estimated risk values.

Types of Studies: TOPAZ has been used within several studies, e.g.

1. Opposite traffic in route structures under conventional ATC (these studies were mainly to learn understanding what is possible with TOPAZ in comparison with other approaches);

2. Aircraft crossing an active runway. These studies have been performed with multiple objectives. One is to learn new ways in modelling multi agent situation awareness issues within accident risk simulations. The other is to apply it to real operations at a large airport in order to allow the responsible persons to make strategic operation design and investment choices. This TOPAZ tool set has been licensed to FAA-AOV, Washington DC.

3. An initial study of free flight equipped aircraft flying within a fixed en-route structure.

4. Risk of collision between two aircraft making simultaneous landings on converging runways. This has been done to allow decision makers at a large airport to re-design an existing operation in order to significantly improve the safety of this operation.

5. Wake vortex risk assessment for aircraft landing on single or parallel runways.

6. An initial study of en-route free flight without the restriction to aircraft of staying within a fixed route structure.

7. An initial study of ASAS time based separation in the TMA (with University of Sao Paulo)

8. Assessing novel descent operations in the TMA on impact on accident risk.

9. Risk of collision between aircraft landing on the same runway (this has been developed by George Mason Univ.)

10. Safety impact of providing automatically generated sound messages to a taxiing pilot (thus without involvement of air traffic controller first).

In addition to these applications oriented studies, several studies have been performed and continue to be performed to further extend and improve the TOPAZ methodology. Studies that have this objective are commonly published to audiences outside the ATM/aviation community."