FAA/EUROCONTROL Cooperative R&D
Action Plan 9

"System Wide Modeling in Fast-time Simulation"

Current and Future Capabilities

Prepared By:

Manuel Miguel Dorado-Usero, Stephane Deycard
Aeropuertos Españoles y Navegación Aérea

Albert Schwartz, Kristina Carr
Federal Aviation Administration William J. Hughes Technical Center

Almira Williams
CSSI, Inc.

September, 2007

Acknowledgements

This report is based on a collection of ideas, experiences, and expertise of the subject matter experts who attended the November 2006 “System Wide Modeling” Technical Interchange Meeting (TIM) in Madrid, Spain. The authors would like to thank the organizations and the attendees listed below for their dedicated involvement and contributions to this effort.

Aeropuertos Españoles y Navegación Aérea (AENA), Spain: Manuel Dorado, Pablo Sánchez-Escalonilla, Patricia López

Boeing Research & Technology Europe (BR&TE), Spain: Ernesto Valls, Isabel del Pozo

Centre d'Études de la Navigation Aérienne (CENA), France: Yann Le Fablec

CSSI Inc., U.S.A.: Almira Williams

Deutsche Flugsicherung GmbH (DFS), Germany: Michael Morr

EUROCONTROL Experimental Centre, France: Marc Dalichampt

EUROCONTROL Headquarters, Belgium: Ulrich Borkenhagen, Thierry Champougny, Gerry McAuley, Catalin Lepadatu

Federal Aviation Administration (FAA) Headquarters, U.S.A.: Diana Liang, Joseph Post

FAA William J. Hughes Technical Center, U.S.A.: Albert Schwartz, Kristina Carr, Karen Buondonno

Ingeniería y Economía del Transporte SA (INECO), Spain: Sara Meson

ISA Software, France: Ian Crook, Abderrazak Tibichte, Matthew Bray

Logistics Management Institute (LMI), U.S.A.: Shahab Hasan

Lockheed Martin, U.S.A.: Pratik Jha

MITRE Corporation, U.S.A.: Pete Kuzminski

National Aeronautics and Space Administration (NASA) Ames Research Center, U.S.A.: Robert Windhorst

National Aerospace Laboratory (NLR), Netherlands: Jos Beers

National Air Traffic Services (NATS), United Kingdom: Hellen Foster

Jeppesen Rail, Logistics & Terminals, Australia: Paul Kennedy

In addition, the authors would like to acknowledge the assistance of the subject matter experts and point of contacts who participated in the interviews/questionnaires of fast-time system wide modeling capabilities. Their inputs were instrumental to our effort by providing detailed information about the capabilities of the existing system wide tools and the availability of the capabilities required for modeling future system wide concepts and initiatives.

ABNA (Airspace BottleNeck Analyzer): Manuel Dorado – AENA

ACES (Airspace Concepts Evaluation System): Robert Windhorst – NASA Ames

Airsecoma Desktop: Edmond Bouchot - Airsecoma

AirTOp: Thierry Salvant - Airtopsoft

AwSim: Lonnie Bowlin, Ron Dlouhy, Andrzej Wrotniak – Aerospace Engineering and Research Associates Inc.

CAASD's system wide modeller: Pete Kuzminski – MITRE Corp.

CHILL: Ian Crook – ISA Software

COSAAC/SHAMAN: Yann Le fablec - Direction des Services de la Navigation Aérienne (DSNA)

FACET (Future ATM Concept Evaluation Tool): Banavar Sridhar – NASA Ames

FAP (including NEVAC): Marc Dalichampt - EUROCONTROL

LMINET: Shahab Hasan and Dou Long - LMI

MENTOR: José M. Lopez-Moncó – AENA; Victor Bustos - INECO

NASPAC: Doug Baart - FAA

NFM (National Flow Model): Matthew Berge, Michael Carter, Bruno Repetto, Laura Kang - Boeing

OPAS: Yann Le Fablec – DSNA

PITOT: José Miguel de Pablo - AENA

RAMS Plus: Ian Crook – ISA Software

SAAM (System for Traffic Assignment and Analysis on a Macroscopic scale): Thierry Champougny - EUROCONTROL

TAAM (Total Airspace and Airport Modeller): Paul Kennedy – Jeppesen Rail, Logistics & Terminals; Users: Jos Beers – NLR, Alfredo Gomez - AENA

TACOT: Françoise Guénin-Rambaud - EUROCONTROL

TOPAZ (Traffic Organization and Perturbation AnalyZer): Henk Blom - NLR

Finally, the authors would also like to acknowledge the contributions of Mark Rodgers from CSSI, Inc. He provided numerous suggestions on how to improve both the readability and content of this report. The authors are very grateful for his insights and assistance.

This page intentionally left blank.

Table of Contents

Page

This page intentionally left blank.

Executive Summary

Under the auspices of 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 fast-time system wide modeling capabilities. The objective of this research was to determine modeling capabilities of existing system wide tools and the availability of capabilities required for modeling future system wide concepts and initiatives.

Exchanging the necessary technical information between practitioners from the U.S. and Europe was recognized as the most efficient way to initiate this effort. Toward that end, a Technical Interchange Meeting (TIM) was organized and held in Madrid, Spain on November 16-17, 2006, hereafter referred to as the 2006 AP9 TIM. The 2006 AP9 TIM provided a forum for subject matter experts to discuss system wide tools used in the U.S. and Europe, present the capabilities of these tools, and to discuss various issues in system wide modeling, including plans for future model development efforts. The two main objectives of the 2006 AP9 TIM included the identification of existing fast-time system wide modeling capabilities, tools and techniques, and the identification of any gaps in these capabilities, tools and techniques relative to sponsoring organizations needs and requirements.

Using the information exchanged during the 2006 AP9 TIM and the information from the 2005 AP9 TIM on Traffic Flow Management (TFM) in fast-time simulation, a questionnaire was developed to facilitate better understanding of the capabilities of existing fast time system wide tools. The questionnaire was used as a guide for interviews conducted by the research team. The participants were also asked to provide comprehensive information about the specific tool(s) for which they had experience.

Responses were received from 15 organizations and 28 subject matter experts; they provided detailed information on 18 fast-time system wide modeling tools. Augmented by information collected from various publications, including FAA and EUROCONTROL documents, the questionnaire and associated interviews provide an increased understanding of the current capabilities in fast-time system wide modeling and the gaps in those capabilities.

The results of the interviews show that current system wide models cover a wide variety of study topics and system wide validation scenarios. However, future system-wide concepts (e.g., CDM and future TFM practices) and other system wide elements (e.g., environmental and weather impacts, and the interaction between infrastructure and operations) still require further developmental activities in order to address known sponsoring organizations needs and requirements. Also, simulation platforms and component or agent based software architectures applied to future tools is a promising way that provides integrated capabilities enabling flexibility at the same time as the consistency in pursuing different objectives via system wide modeling.

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 research priorities in terms of common actions and agendas that would support both organizations. The Committee identified several areas of mutual interest where the FAA and EUROCONTROL would work together on R&D cooperative tasks referred to as ‘Action Plans’ (APs).

Action Plan 9 (AP9), “Air Traffic Modeling of Operational Concepts”, is one of those action plans. Its 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, and;

5) To promote best practices and lessons learned in the use of fast-time simulation models by U.S. and European partners.

Action Plan 5 (AP5), “Validation and Verification Strategy”, is another cooperative action plan. Its objective is to determine a strategy for validating and verifying the performance, reliability, and safety of Air Traffic Management (ATM) systems and any potential relationship to these issues may have for 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.

Research activities for both AP5 and AP9 were identified to support these objectives; past activities included the AP5 Workshops and AP9 Technical Interchange Meetings (TIM). These activities addressed the topics of concept validation, scenario development, fast-time simulation architectures, and current and future modeling and simulation capabilities. Following each of these activities documentation was developed that identified common practices, lessons learned, modeling gaps, and current and future fast-time infrastructures.

Activities were chosen based on the mutual needs and requirements of the FAA and EUROCONTROL Action Plan leads. The identification of system wide models and their current and future capabilities were included as part of AP9. A TIM was held between practitioners from the U.S. and Europe to facilitate a better understanding of the current and future required capabilities of system wide models. In addition, a questionnaire was developed and subsequent interviews were conducted to identify the capabilities of the existing system wide modeling tools and the gaps in those capabilities relative to known sponsoring organizations needs and requirements.

2 2006 AP9 TIM

The 2006 AP9 TIM, "System Wide Modeling", provided subject matter experts (SME), tool developers, users, and decision makers with a forum to discuss present and future capabilities of their system wide modeling tools, and to discuss significant issues in system wide modeling. The objective of the TIM was to determine the modeling capabilities of existing system wide tools and the availability of capabilities required for modeling future concepts and initiatives and their corresponding system-wide impacts.

More than 28 representatives from the FAA and EUROCONTROL Headquarters (HQ), FAA William J. Hughes Technical Center, Aeropuertos Españoles y Navegación Aérea (AENA), Boeing Research & Technology Europe (BR&TE), Centre d'Études de la Navigation Aérienne (CENA), CSSI Inc., Deutsche Flugsicherung GmbH (DFS), Ingeniería y Economía del Transporte SA (INECO), ISA Software, Logistics Management Institute (LMI), Lockheed Martin, MITRE Corporation, National Aeronautics and Space Administration (NASA) Ames Research Center, National Aerospace Laboratory (NLR), National Air Traffic Services (NATS), and Jeppesen Rail, Logistics & Terminals participated in presentations and discussions on fast-time system wide modeling. The 2006 AP9 TIM provided an excellent forum to facilitate communication between system wide modeling analysts and developers, hereafter referred to as practitioners. The emphasis was placed on fast-time system wide simulation and associated modeling practices in the U.S. and Europe.

The 2006 AP9 TIM also provided insight into the needs of practitioners that are not captured in the modeling literature or previous surveys of fast time system wide modeling tools. These insights include analysis concerns regarding uncertainty, validation, platform simulation, and process models.

The 2006 AP9 TIM was structured to allow practitioners to present information on their system wide tools and processes. Each presentation was approximately 30 minutes long with an additional 15 minutes for questions/answers and discussions. A brief summary of each presentation follows:

2.1 Presentations

Presenter: Joseph Post (FAA)

Topic: System Wide Modeling Requirements from the FAA HQ Point of View

Joseph Post started with an overview on the uses of system wide modeling tools and a summary of existing tools within the FAA which stimulated many discussions at the 2006 AP9 TIM. FAA typically uses system wide models to support large acquisition programs by providing information on requirements, cost-benefit, research and development, and performance analysis. The list of existing models included: NASPAC, systemwideModeler, Airspace Concepts Evaluation System (ACES), Future ATM Concept Evaluation Tool (FACET), LMINET, and AwSim (all of which are represented in this document). The presentation then concentrated on current modeling shortfalls and requirements; this information was incorporated into the questionnaire and is elaborated on in Section 4.

Presenter: Thierry Champougny (EUROCONTROL HQ)

Topic: System for Traffic Assignment and Analysis on a Macroscopic scale (SAAM)

Thierry Champougny provided a description of the SAAM tool suite and examples of the types of analysis that could be performed using SAAM. SAAM is an integrated and modular system of tools that can evaluate system performance and other metrics Europe-wide. One of the key components to SAAM is a tool that optimizes traffic flow Europe-wide. SAAM also has an extensive graphics capability, including animation of scenarios. A more detailed description of SAAM is provided in Section 3.

Presenter: Shahab Hasan (LMI)

Topic: System-wide Modeling for the Joint Planning and Development Office (JPDO)

Shahab Hasan presented an introduction to the JPDO, its Evaluation and Analysis Division (EAD), and the Next Generation Air Transportation System (NextGen) concept (previously referred to as NGATS). The EAD team was formed to assess strategies for transforming the National Airspace System (NAS) to meet high-level national goals. The presentation also included descriptions of the current tools used by the EAD. The presentation was concluded with the description of two analyses: 1) Constraints analysis – examining the primary factors limiting NAS performance with respect to both capacity and environmental constraints; and 2) Portfolio analysis – quantifying how well the NextGen investment portfolio meets NextGen goals. A description of LMINET, one of the models in the EAD tool suite, is provided in Section 3.

Presenter: Ian Crook (ISA Software)

Topic: System-wide Fast Time Simulation (FTS) Architecture

Ian Crook presented a fast-time simulation architecture for system-wide analysis. The presentation started with a description of the Common ATM Information State Space (CAISS) which provides a solution to the storing and retrieval of vast amounts of system-wide information. The second part of the presentation discussed the Strategy for Information Management and Collaboration (SIM-C) architecture and provided several analysis examples. SIM-C is supported by a network-centric modeling infrastructure that has been used for analysis of System Wide Information Management (SWIM) concepts, flight-object concepts, publish/subscribe enterprise architectures, and En Route Automation Modernization (ERAM). A description of RAMS Plus, which is used in the SIM-C environment for system wide modeling, is provided in Section 3.

Presenter: Pete Kuzminski (MITRE CAASD)

Topic: System-wide Modeler

Pete Kuzminski presented the latest model in the MITRE Center for Advanced Aviation System Development (CAASD) tool-set called systemwideModeler. The systemwideModeler is used in support of investment decision-making activities, including benefits assessment, alternatives analysis, and problem prediction. The model uses resources (e.g., airports, en route sectors, terminal, corridor, ground delay programs, airframe) to simulate the system and issue system constraints. A unique resource used by the model is the Traffic-Sensitive Sector Impedance Model (TSSIM) which takes into account multiple variables (including workload) to develop sector capacities. A description of the systemwideModeler is provided in Section 3.

Presenter: Manuel Dorado (AENA)

Topic: System-wide Modeling initiatives in Europe

The previous presentations by Mr. Post and Mr. Hasan focused on the U.S. perspective of system wide modeling and future concepts; this presentation by Manuel Dorado focused on the European perspective of system wide modeling and future concepts, including the European future concept, SESAR. The presentation started with key ideas and the scope of system-wide modeling in Europe. The focus then changed to SESAR which is the "operational" piece of the Single European Sky (SES) legislation. SESAR is a proposed approach to reform the ATM structure in Europe. Mr. Dorado then provided examples of system wide modeling analysis in Europe. The conclusion of his presentation included a list of groups that will be identifying gaps in required system wide modeling capabilities.

Presenter: Marc Dalichampt (EUROCONTROL EEC)

Topic: FAP Model

Marc Dalichampt presented the Future ATM Profile (FAP) tools. FAP is a core component of the European capacity management process. The presentation described how the FAP tools are used in the Pan European capacity planning process and provided an overview of the FAP tool architecture. This included an explanation of the simulation tools used within FAP, the analysis methodology, and some sample projects. A description of FAP is provided in Section 3.

Presenter: Robert Windhorst (NASA Ames)

Topic: System-wide Modeling with ACES

Robert Windhorst presented the ACES suite of models (software agents) and associated modeling infrastructure. The primary purpose of ACES is the evaluation of concepts. An overview of ACES was presented as well as an example of a concept assessment. A description of ACES is provided in Section 3.

Presenter: Sara Meson (INECO)

Topic: CDM Process Simulator

Sara Meson presented the Process Management Simulator (PROMAS) project. Although not a system wide tool as defined by the scope of the 2006 AP9 TIM, it did provide insight into the area of process management. The objective of the project is to develop a modeling tool to simulate the roles and process management of a system. Additional information on process Modeling is provided in Section 3.

Presenter: Kevin Corker (SJSU)

Topic: Human Performance in System-wide Modeling

Kevin Corker's presentation addressed the topic of human performance in four sections. First, he addressed the importance of modeling human performance at a system level. He discussed mechanisms of human performance, prediction of performance, determining perceptual, cognitive, and motor requirements, and exploring augmentation of performance. Dr. Corker concluded that the last two items, motor requirements and augmentation of performance, were too detailed to be examined at a system wide level. The second section addressed what attributes of human performance should be modeled at a system wide level. Here he focused on the first two areas mentioned above, the mechanisms of performance and the prediction of performance. Third, he presented his perspective on modeling methods appropriate for assessing human performance at a system-wide level. And finally, he identified next steps regarding the assessment of human performance at a system wide level.

Presenter: Diana Liang (FAA HQ)

Topic: WITI and System Operations Perspective

Diana Liang made the final presentation on the topic of weather. The presentation focused on the NAS weather index (an extension of the Weather Impact Traffic Index (WITI) research). The object of this index is to compare NAS performance over differing time intervals with differing weather and demand. The presentation described the tool that calculates WITI and the analysis capability of the tool.

The above described presentations can be found on the following website:
http://www.tc.faa.gov/acb300/ap5_workshops/action_plan5_9.html

3 System-wide Modeling Scope

To establish a common understanding of system wide modeling, the sponsors and the organizers of the 2006 AP9 TIM established the following TIM scope and elements.

- Scope
    - "System wide" is equivalent to runway-to-runway operations (US) or to gate-to-gate operations (European)
    - Focus is placed on system operations as opposed to economic, financial or political attributes of the ATM system.
    - Focus is placed on high-fidelity system wide modeling capabilities that capture propagation of a problem throughout the system, and support modeling of future operations, technologies and concepts.
- Elements
    - Time Horizon
        - To evaluate system dynamics during a day of operations
        - To assess system capabilities assuming the infrastructure and procedures that are available or are able to be implemented today; complex changes in infrastructure will likely require significant changes in modeling capabilities, and will need to be initially investigated using higher level/lower fidelity system wide models.
    - Flights
        - 4D flight trajectories
        - Aircraft performance characteristics
        - Equipage issues
        - Performance based operations
        - Flight schedule and future demand modeling is considered an input to a system wide model (as opposed to being considered a system wide modeling capability).
    - Airports
        - Arrival and departure traffic management
        - Airport surface/ground movements
        - Gate operations
    - Terminal areas
        - Approach and departure trajectories
        - Approach and departure traffic management
        - Corner fixes/important waypoints
        - Terminal capacity
    - Airspace
        - Regions and domains: ground capability/separations standards and procedures, en-route vs. oceanic, user-preferred routes vs. flex/fixed tracks, etc.
        - Traffic Flow Management (TFM)
        - Dynamic airspace configurations (excludes the logic behind the dynamic airspace concept; supports the ability to investigate different dynamic sectorization schemes)
    - Environment

        - Infrastructure (impact on operations)
        - Weather
        - Special Use Airspace and Temporary Flight Restrictions
        - Aeronautical information, including LOA, etc.
        - Mixed equipage issues (or performance based operations)
            - Different equipage (technology vs. equipage)
            - Equipped and non-equipped aircraft
        - Current and future operations and procedures
        - Noise and emissions (mostly as a limitation; for instance, a cap on the available resources)
        - Transition to NextGen and SESAR
    - Decision Making
        - Air-carriers/Airline Operations Center (AOC) (as applicable to flight efficiency and recovery, but not planning or scheduling)
        - ANS Providers (ANSP)
        - Other Air Traffic Control (ATC)/ATM related positions (e.g., TFM, MSP)
        - Pilots
        - Information exchange (data requirements, etc.)
        - Inter-operability issues (performance of different tools that work on the same issue; data availability: accuracy, timelines, etc.)
    - Human Involvement
        - Task-load: what exactly is done
        - Workload: can it be done
        - Pilot vs. controller: roles and responsibilities, integration issues, resolving the off-nominal conditions, failure mode, etc.
        - Automation vs. human: roles and responsibilities, integration issues, resolving the off-nominal conditions, failure mode, etc.
    - Performance assessment
        - Metrics
        - Measures
        - Connectivity to FAA's Flight Plan and similar docs
    - Other issues
        - Interoperability between models
            - Is there a tool that does it all, or;
            - Do the inputs/outputs of various models assure the ability to sequentially run a scenario through several models in order to get the whole picture
        - Is it possible to enhance the modeling of real-world challenges faced by ANSP's in order to provide simulation results that more closely reflect ANSP performance
            - Differences in behavior between different air-carriers; for instance, some are willing to fly closer to a bad weather cell than others

- Unforeseen effects of initiatives in the real-world; for instance, limitation of the ground delay programs by focusing only on the large airports (Chicago vs. Midway)

Section 3.1 "Tool Description", provides information on the tools that were investigated via the questionnaire and interview process; these tools fit within the scope established above. Section 3.2, "Platform Simulations" and section 3.3, "Process Models" do not directly fit into the above scope; however, since they are valuable modeling tools supporting other aspects of system wide investigations, a brief description of several such tools was also included.

3.1 Tool Description

This section provides a brief description of the tools investigated by the AP9 System Wide Modeling Survey. These tools are a representative sample of the system wide tools currently used by government, industry, and academia.

Each tools' architecture, primary objectives and main calculations are summarized below. In addition, contact information is included for each of the tools should the reader require further information.

Airspace BottleNeck Analyzer (ABNA)

ABNA is a macroscopic queuing model. It models airspace and airports as a network; airspace sectors and airports are represented by nodes with a specified capacity. ABNA's primary purpose is to analyze bottlenecks system wide, including measuring flight delays in an Air Traffic Flow Management (ATFM) type scenario.

ABNA is a continuous (time-based) simulation model with a modular architecture and is normally coupled with RAMS.

Contacts: Manuel Dorado, mdorado@aena.es

Airspace Concepts Evaluation System (ACES)

ACES is a deterministic agent based tool whose primary purpose is to support system wide benefit assessments of ATM technologies and concepts. ACES calculates a variety of metrics, including 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 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.

ACES has an agent based infrastructure that uses publish and subscribe messages to trigger interaction between agents. It is a distributed scalable simulation that facilitates incorporation of new agents that impose new requirements or improved logic.

Contacts: Robert Windhorst, rwindhorst@mail.arc.nasa.gov

Airsecoma Desktop

Airsecoma Desktop is a continuous (time-based) simulation and analysis tool. Its primary purpose is to support ATC Configuration Management, which automatically generates ATC sector configuration schemes adapted to the traffic demand and manpower resources.

Airsecoma evaluates capacity restrictions through the management of sector overload. It performs sector configuration management and optimization, by balancing capacity and demand, and is capable of simulating a multi-sector planning function. It handles macroscopic (aggregated traffic flows) and microscopic (flight by flight) traffic demand.

It is a modular application using .xml or .dll files.

Contacts: Edmond Bouchot, Edmond.bouchot@airsecoma.com

AirTop

Airtop is a gate-to-gate continuous fast-time simulator, with a multi-agent architecture. It can simulate en-route, approach and ground operations, and combinations of the three. Airtop evaluates, among others, capacity, delay, flight efficiency, safety and controller workload related metrics.

It is developed using an object-oriented, multi-agent architecture. It is an open tool with an Application Programming Interface (API) that allows the user to modify/substitute/add elements.

Contacts: Thierry Salvant, Thierry.salvant@airtopsoft.com

AwSim™

AwSim™is a suite of trajectory simulation, conflict prediction, and metric evaluation tools that have been developed to perform a variety of air traffic simulation and evaluation tasks. It has been developed as a tool to quantify, through simulation and data analysis, the response to a given air traffic situation within a predefined airspace structure, resulting from controlled changes to the input parameters for the trajectories or the airspace configuration. The primary purpose is to measure macroscopic changes in the airspace system (e.g., changes in structure, procedures) and how they impact the system in terms of safety (i.e., conflict analysis and conflict density).

AwSim™ is a stochastic model employing Monte-Carlo algorithms to model random events. It has an open, agent-based architecture where the user can add modules, components or agents.

Contacts: Lonnie Bowlin, lonnie.bowlin@freeflight.com

CAASD's systemwideModeler

CAASD's systemwideModeler is a discrete and deterministic fast-time simulation of the NAS that models individual flights and their impedance due to congestion at airports, TRACONs, and sectors as well as certain traffic management initiatives. Its primary purpose is to help analysts estimate changes in load and delay due to changes in NAS operations. Its primary unique feature is a workload-based sector impedance model. Collaborative Routing & Coordination Tools (CRCT), a trajectory modeler, is used as a systemwideModeler's pre-processing step.

Contacts: Pete Kuzminski, petekuz@mitre.org

CHILL / SIM C

SIM C is an infrastructure developed to operate and allow communication between the ISA software in-house tools; it supports SWIM and Net Enabled Operations (NEO) analysis.

CHILL is the first demonstrator to use a client interface for a CDM (Collaborative Decision Making) simulation. It distributes an identified problem to various agents (stakeholders or functions, such as Aircraft Operators, ATC, ATFM, etc.), and can be used for both Human-in-the-Loop (HITL) gaming exercises and FTS agent based CDM simulation.

The tool evaluates capacity, delay, flight efficiency, environment and controller workload related metrics.

CHILL is an agent-based tool using API's for communication through SIM C.

Contacts: Ian Crook, ian@isa-software.com

COSAAC/SHAMAN

COSAAC (aka SHAMAN) is an analytical tool, with an objective of supporting TFM, delay and slot allocation simulations, and analysis of traffic flows and modifications (e.g., increases in traffic, rerouting, etc.). Its main algorithm is based on CASA (European TFM real algorithm).

COSAAC evaluates delay related metrics.

Contacts: Yann le Fablec, lefablec@cena.fr

Future ATM Concept Evaluation Tool (FACET)

FACET is a flexible ATM simulation environment that has been established for exploring, developing, and evaluating advanced ATM concepts. The primary evaluation objective that the system assesses is capacity and to a lesser extent economics (delays).

FACET requires MySQL to access the Database and uses message passing to integrate with other tools.

Contacts: Banavar Sridhar , bsridhar@mail.arc.nasa.gov

FAP (NEVAC)

FAP is a methodology, based upon a set of tools, one of them being NEVAC.

FAP is mainly used for capacity planning: European Convergence and Implementation Plan (ECIP)/Local Convergence and Implementation Plan (LCIP) planning. It is used for ATFM studies, with the ATFM simulator AMOC/GASEL, or NEVAC.

It provides capacity, delay and flight efficiency calculations.

The NEVAC architecture is organized around the following components: a kernel component for algorithms, a process component for data management and a GUI layer containing a generic 2D ATFM map component. There are six components, four components encapsulating specific algorithms, one component encapsulating ChartDirector-based charts and one final component defining NEVAC-specific Qt GUI widgets.

Opening the architecture to allow for the use of external components is planned for the future.

Contacts: Marc Dalichampt, marc.dalichampt@eurocontrol.int

LMINET

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.

Contacts: Shahab Hasan, shasan@lmi.org or Dou Long, dlong@lmi.org

MENTOR

MENTOR is a macroscopic model, with two main objectives: bottleneck detection, and demand/capacity ratio analysis in sectors. Its main applications are capacity planning, system bottleneck identification, sectorization scheme planning, and route network optimization.

It is currently used to plan and optimize sectorization schemes in Spain ACC's.

It calculates capacity and delay.

It is a partially modular design with restrictions on data flow.

Contacts: José Manuel López-Moncó jmlmonco@aena.es; Victor Bustos, vbustos@ineco.es

NASPAC

NASPAC refers to an integrated set of computer program modules designed to model the entire National Airspace System, the en route structure and traffic flows, as a network of inter-related components, reflecting the effects of weather conditions, air-traffic control procedures, and air-carrier operating practices. NASPAC uses a mixture of intelligent error-checking, high processing speed, and fine tuned control of simulation runs to accelerate assessments of NAS performance.

Contacts: Doug Baart, douglas.baart@faa.gov

National Flow Model (NFM)

The Boeing National Flow Model (NFM) is a large-scale simulation of aircraft flow in the 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 (i.e., input as tail-routed schedules) on the day of operations, airport arrival rate limits, airport departure rate limits, and sector occupancy limits. It 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.

Contacts: Mathew Berge, matthew.e.berge@boeing.com

OPAS

OPAS is a family of tools for fast time simulation: OPAS En-Route, OPAS TMA, and OPAS Coupled (En-Route + TMA).

OPAS En-Route can be used for conflict, capacity, workload and sectorization analysis.

OPAS calculates delay and controller workload.

It possesses a modular architecture, with several libraries which can be used in any of the OPAS tools.

Contacts: Yann le Fablec, lefablec@cena.fr

RAMS Plus

RAMS PLUS is an ATM gate-to-gate fast time discrete event simulation tool (airport, en-route, approach, and combination of the three).

It allows for capacity, delay, safety, flight efficiency and controller workload calculations.

It's a modular tool, using .xml and support messages.

Contacts: Ian Crook, ian@isa-software.com

SAAM

SAAM is an Airspace Design Simulation tool. It is a modular and flexible application built with a kernel that includes integrated tools. SAAM offers airspace designers the ability to design European Airspace Structure (e.g., Route, Sectors, Runways, Restrictions) and to test any kind of airspace structure with any traffic demand in all Europe.

SAAM has a many functions to analyze solution in terms of sectors overloads, workloads, traffic density, conflict density, route efficiencies, complexity, and environmental gas emission. In addition, SAAM provides an integrated GIS platform supporting 2D, 3D and 4D visualization capabilities, including animation.

It supports delay, safety, flight efficiency, environment and workload calculations.

Contacts: Thierry Champougny, Thierry.champougny@eurocontrol.int

Total Airspace and Airport Modeller (TAAM)

The Total Airspace and Airport Modeller (TAAM) is an ATM gate-to-gate fast-time discrete event simulation tool (i.e., airport, en-route, approach, and combinations of the three).

This model can be used to simulate realistic air traffic control scenarios in fast-time and provides measures of flight efficiency, workload, capacity, punctuality, delay.

Contacts: Paul Kennedy, paul.m.kennedy@boeing.com

TACOT

TACOT is used for pre-operational studies. It is a simulator based on the ETFMS operating system, with a unique feature that supports the reproduction of the ETFMS slot allocation process. It performs delay calculations. TACOT is a stand alone procedural based application.

Contacts: Françoise Guénin-Rambaud, francoise.guenin@eurocontrol.int

Traffic Organization and Perturbation AnalyZer (TOPAZ)

TOPAZ (Traffic Organization and Perturbation AnalyZer) is a safety calculation tool.

TOPAZ is used to estimate optimum safety levels in terms of well defined accident and/or incident events as a function of capacity related parameters. TOPAZ also provides an estimation of the bias and uncertainty in the estimated risk values.

Contacts: Henk Blom, blom@nlr.fr

3.2 Platform Simulations

System wide simulation is conducted more and more using Platform Simulations. In these cases stand alone simulation tools are coupled with other components, such as agents, modules and functionalities that provide different ATM features to the simulation independently. The platform itself is normally a communication layer, kernel, or an application server that provides on-line and/or off-line integration and data interchange between the different components of the simulation.

Future concepts, particularly those affecting the overall system, are normally candidates for specific functionalities or models that might need a simulation platform that allows for integration.

In the responses to the questionnaire presented in this document, SAAM and PITOT stand out as two examples of the Platform Simulations. They use very diverse technologies, software architectures and philosophies.

SAAM, developed by EUROCONTROL Route Network Development Sub-Group (RNDSG), is an Airspace Design Simulation set of tools. It is a modular application built with a kernel of integrated modules, justifying its classification as a Platform simulation. SAAM is based on an analytical kernel that calculates trajectories based on flight plans and performances. The effect of any new structure, restriction or concept affecting trajectories can be implemented in a separate module; once integrated in the SAAM simulation, this module will interact with other components in a system wide simulation to produce the resulting effects on flight and system performance. SAAM supports evaluation of different airspace structure designs (e.g., route, sectors, runways, restrictions) for any expected traffic demand across Europe. The traffic can be assigned to airspace structures based on different airline criteria (e.g., shortest path, cheapest path) or based on the lowest cost for the overall community (e.g., optimum path generated by considering both airlines & ANSPs). SAAM has many functions that evaluate sector overloads, workloads, traffic density, conflict density, route efficiency, complexity, environmental gas emissions, and other metrics. In addition, SAAM provides an integrated Geographic Information System (GIS) platform supporting 2D, 3D and 4D visualization & presentation, including animation. These are separate modules that can be used on the SAAM platform.

PITOT is a simulation platform providing on-line and off-line integration of simulation tools, modules, components, agents and processors. Its objectives are to: 1) generate optimal solutions by linking the simulation and analysis tools and using automated iterative loops; 2) provide one unique data model (ATM model); 3) isolate the user from software and data issues by building a human-machine interface layer which allows modeling ATM operations without having to know file systems, programming concepts, and formats (ultimately, PITOT will also include functionalities facilitating better understanding, integration and translation of the limitations of each tool included in the platform); 4) enable easy evolution: metamodel (evolvable open model) instead of a fixed ATM model; 5) test real system components, for instance Decision Support Tools that can be integrated in the platform as if they were fast-time simulation modules; and finally, 6) integrate model based simulators (fast-time) with HITL (real-time) simulators to enable simulation exercises, in which some parts of the system (e.g.: some sectors) are simulated by real system components such as controllers, while other parts (e.g., adjoining ACC) are simulated by modeled components playing the role of virtual elements. To deal with all these objectives PITOT uses a platform simulation based on a component/agent based software architecture, which enables on-line integration (i.e., on-line data exchange between components), together with a workflow engine architecture, which enables off-line integration (i.e., stepped execution of tools and data exchange based on file reading and translation into a common database). PITOT is open to integration of both PITOT-in-house elements and outside components (e.g., commercial tools).

Simulation platforms are not normally addressed as simulation tools since the platform itself does not provide any simulation results. In addition, all modeling, concept behavior functionality and analysis capabilities are not included in the platform but within their components. In other words, the platform will not provide any results if the components are not present. The main goal of Platform simulations is that they provide an open and flexible way to address the simulation of new concepts by developing the concept functionality in a separate component, and integrating it into the overall model already integrated in the platform. This is the most efficient solution in accessing system wide concepts with system wide simulations.

3.3 Process Models

When conducting the analysis and validation of future ATM system wide concepts, operational issues and system performance are typically the key elements. However, even if a benefit potential is demonstrated for the system performance, the system wide processes which might involve numerous organizations, roles and agents with different perspectives and objectives, may not be realized or may be difficult to implement. So, in the context of system wide processes, such as Collaborative Decision Making (CDM) or User Driven Prioritization Process (UDPP), the process itself needs to be evaluated from both a performance (operational) and process viability (organizational and managerial) point of view.

Since the objective of this research is to focus on operational system wide tools, process models have not been addressed in detail. However, due to their significance to future system wide concept evaluation (such as NextGen in the U.S. or SESAR in Europe), a brief description of process models is included in this section.

In Europe, three types of process models are deemed viable for process analysis; 1) HITL gaming platforms, 2) automated gaming models (fast time simulation), and 3) process management models. The platform CHILL is an example of both a HITL gaming platform and an automated gaming model. Within CHILL, processes are evaluated by running a real-time simulation where different roles (e.g.: airline dispatcher, low cost operator, Flow Management, etc.) can act and make decisions on a flight-by-flight basis. Supported by agent based software architecture, CHILL can also acts as a fast-time simulator for processes in which humans are substituted with automated agents. Thus, this type of platform can run fast-time simulations providing quantitative results for operational performance and also process viability analysis. The third type of process model, process management models, can also conduct system wide simulations, but are normally focused on modeling only the processes that compose the ATM system or new concept. These models do not normally model flights and trajectories when investigating a new concept, but the processes, organizational and managerial changes resulting from an implementation of a new system wide concept. PROMAS is one example of a process management model; it is under development by INECO and AENA for use in validation exercises of SESAR European future concepts. PROMAS can model flights and operations; however its intended objective is to properly address the impact and viability of new concepts on managerial processes.

4 Current Capabilities and Gaps in System Wide Modeling

The 2006 AP9 TIM provided a necessary starting point in capturing the system-wide modeling capabilities found in current simulation models and identifying gaps in those capabilities.

After the 2006 AP9 TIM, an extensive questionnaire (more than 250 questions) was developed to gather a diverse set of information related to system wide modeling. The questionnaire was used as the basis for on-site and telecom interviews with developers and practitioners of all the tools summarized in this section.

Section 4 provides a summary of the information gathered in the questionnaire and associated interviews. It is formatted to follow the sections as they appeared in the questionnaire. However to provide a more consistent document certain responses, specifically those concerning weather in Section 4.9, have been moved to other sections of the document.

4.1 Section 1 – General Modeling Information

4.1.1 Section Description

The first section of the questionnaire provides general information on the tools. It included tool descriptions, high level objectives, acceptance of external calls from other programs, metrics, potential enhancements, and the ability to model delay propagation. Each of the tools is described in Section 3.1.

4.1.2 Current Capabilities

The tools were described as either discrete event, continuous (time-based), agent-based, and/or analytical. The responses showed that most of the tools could be described as either discrete event or time-based. Only a few tools were agent-based or purely analytical. About half of the tools were stochastic. However, among the deterministic tools, some developers indicated that they are working toward a stochastic version of their tool. This trend indicates that Monte-Carlo methods are needed in order to deal with the uncertainty in complex-dynamic systems. However, this requirement is not applicable to a couple of European tools that are dedicated to reproducing the behavior of Central Flow Management Unit (CFMU) processes; here, a purely deterministic approach is required. CFMU regulation processes produce a unique deterministic solution for each congestion problem; therefore, CFMU simulation tools must use deterministic algorithms.

Most of the tools produce a detailed log, standard reports, and provide some type of graphics and/or animation capability. However, only a few provided any type of optimization. The optimization routines typically considered included fuel burn, conflict-free trajectory generation, sector configuration, conflict resolution, and economic factors (e.g., delay).

Among the performance metrics that the tools calculated, capacity and delay were the primary focus, with flight efficiency also being considered. Predictability, the ability to determine the variation in the system; flexibility, how well the system accommodates the user; environmental metrics such as fuel burn and emissions; and complexity, a measure of how complex the system is, are found in only a few of the tools surveyed. Environment and safety are hardly covered at all within the surveyed tools. Only a few of the tools surveyed considered controller workload; however, when it was considered it is typically limited to taskload as opposed to cognitive controller workload. As indicated previously, capacity and delay are the primary focus of current tools; however many of the practitioners noted a problem regarding the identification of what metrics to collect, apparently due to a lack of agreed upon definitions and standard performance metric indicators.

An important issue is the ability to model delay propagation which calculates delay on a single airframe through many legs during the day. This is important in that an airframe that becomes delayed on one leg may not depart from its departure airport at its scheduled departure time which affects the demand on the system. In most cases the tools surveyed could consider delay propagation given the required data on flight-connectivity.

One additional question addressed in the general section regarding the ability of the tool to accept external calls will be also addressed in section 4.12. The final question dealt with the future enhancements to the tools. All the models surveyed had planned enhancements, including dynamic rerouting, workload calculation, integration with other tools, better conflict detection and resolution, and other internal enhancements.

4.1.3 Gaps and areas of research

Most of the capabilities discussed in this section were for information only, therefore there were no identified gaps. However, during the TIM two important issues were identified and discussed below: 1) Sensitivity Analysis and 2) Validation.

Sensitivity analysis– Sensitivity analysis represents an assessment of how the variation in the output of the tool can be apportioned, qualitatively or quantitatively, to different sources of variation. It was noted above that many of the tools provided stochastic distributions in the input data or processing of that data. This is a requirement since the system is complex and does contain many uncertainties (e.g., time of departure for example). But what happens to the output (e.g., delay) when you vary the departure times? Performing a sensitivity analysis can determine the confidence one has in the results. Sensitivity analysis is a lengthy process requiring multiple simulation runs. In many cases practitioners do not have the time or resources to perform sensitivity analyses. This, of course, is an organizational issue outside the scope of this document. On the other hand, sensitivity analysis normally becomes practical when several simulation runs can be conducted (e.g.; 20 simulation runs could cover a statistical level of confidence for airport delay, including sensitivity of delay to traffic variations). However, as noted above, practical does not always mean feasible due to lack of time and resources. In that case, automation of simulation processes may increase the feasibility of conducting required sensitivity analyses (by providing the ability to run and process massive amounts of simulation data). Simulation platforms address the issue of large scale automated simulation runs for sensitivity analysis (i.e. PITOT, described in section 3.2, automates simulation processes involving several tools in order to produce massive simulation runs).

Tool Verification and Validation - Within the aviation community, models are used to provide solutions for analysis, synthesis and instrumentation. Regardless of the purpose, the intent is to conduct a successful simulation(s) that produces sufficiently credible results that they are accepted and used by decision makers [1]. Industry practices dictate that in order to substantiate adequate confidence in the tool that verification and validation activities must occur. Verification and validation are different activities in that verification assesses the transformational accuracy (i.e., did we build the system right?) of a tool and validation assesses the behavioral aspects (i.e., did we build the right systems?) of a tool. However, theses activities can be integrated throughout the development lifecycle. Ideally, verification and/or validation should be performed prior to tool use. However, it seldom occurs for various reasons. Most practitioners agree that, moving forward, verification and validation (V&V) are essential activities that should be incorporated into tool development if credence is to be given to the accuracy of the models. Several models investigated followed certain validation processes, but, since the models can be quite complex, sometimes not all results and processes included in the model are properly validated. Once the model is in use, several practitioners and developers conduct calibration runs (comparing simulated results with real-world results) in order to validate elements of the model; these may include specific results, a new methodology in use, accuracy, variance, level of confidence, variability of results, and correlation with certain previously validated values. A related topic that was not addressed was certification. In the absence of verification and validation certification cannot occur.

4.2 Section 2 – Airspace

4.2.1 Section Description

The Airspace Section of the interview focused on fast-time modeling capabilities relating to airspace structure, restrictions and operations; it covered questions about modeling the en route and terminal environments, approach and departure procedures, modeling of sectors, sector capacities, Special Use Airspace (SUA), altitude restrictions, capacity-demand imbalances, and performance-based airspace operations and restrictions.

4.2.2 Current Capabilities

Typically, the tools use the same logic for simulating the operations within en route, terminal and the approach and departure airspace segments. Only one tool differentiates between the en route and terminal environments by representing the former as 3-D airspace segments and the latter as node-link structures; in addition to enabling use of different separation standards in en route and terminal airspace segments, this approach also enables investigation of traffic flow interactions in en route segments. Tools that do not have this capability simplify terminal operations modeling by using very high capacity limitations in this airspace. In a few instances the terminal environment is not modeled, depending on the main objectives of the specific tools.

Most of the interviewed system wide tools process airspace structure, restrictions and operations in two steps. In the first step, geo-coordinates and altitude restrictions of airspace sectors and flight trajectories are mapped against each other to determine the ordered list of sectors each flight will traverse on its path from origin to destination. In the second step, only the ordered lists are considered and airspace sectors are typically modeled as points or queues with a known capacity and defined average transit time value. This approach does not consider the geometries of multiple flight trajectories and the impact they may have on each other, but provides a high level view of the traffic situation across the examined airspace.

Other tools process airspace structure, restrictions, and operations using a more detailed approach; throughout a run, these tools continually consider both flight trajectory and airspace definitions data, and evaluate the location of each aircraft relative to other flights, airspace resources or severe weather cells. Some of these tools are also capable of rerouting aircraft as needed to avoid conflicts with other flights or severe weather cells. Conflict resolutions and severe weather avoidance are rarely available. Typically, tools are capable of detecting conflicts, but only few are capable of resolving them. Only two of the US tools were capable of providing conflict resolutions through speed or altitude adjustments, or path stretch, while around a third of the European tools are able to address conflict resolution through mathematical equations, delay application, or rule-based actions. Severe weather avoidance, on the other hand, is available in several tools, and is typically modeled by providing a route around the bad weather based on SWAP routes or generic re-routes specified via input data.

When enforced, sector capacities are typically modeled as a Monitor Alert Parameter (MAP) or some other input specified values. In most of the tools, the sector capacity can be user-defined. Some of the tools addressed in the interview only record the instantaneous sector loads and do not have the ability to limit the number of aircraft in a sector. Other tools, however, are able to enforce sector capacity limitations: when sector capacity is reached, these tools will typically mimic holding flights "at sector boundary" by adding delay to their flight time or, more frequently in Europe, the system will react by applying ground delays (based on CFMU processes).

Finally, logic used to simulate airspace operations and limitations rarely considers the human performance implications. Only one tool at this time incorporates the limitations due to human involvement by considering the tasks performed by air traffic controllers; typical tasks and duration of these tasks are considered for each flight in each of the modeled airspace sectors, and the capacity of individual airspace sectors is limited by controller's ability to perform these necessary tasks in the available time frame.

4.2.3 Gaps and areas of research

The single most important gap in modeling capabilities related to airspace structure, restrictions, and operations is the lack of objective sector capacity assessment. Most of the investigated US tools were not capable of determining the capacity of an observed airspace unit as a function of either traffic flow complexity or human (air traffic controller) performance limitations. The same trend stands in Europe, but such calculations are proposed for integration in two of the tools.

In addition, even though capabilities to model flight behavior as a function of onboard equipage and airspace limitations are slowly emerging, the existing ones are not flexible enough to support the modeling of performance-based airspace operations. The lack of clear definitions and requirements for performance-based operations was frequently stated by the developers as the main reason for not integrating such capabilities at this time; however, fast-time simulation is a likely cost-efficient means of investigating the pros and cons of this new concept. Therefore, modeling capabilities for performance-based airspace operations need to be developed in a manner that will enable investigation of different ways of potential concept implementation and, thus, facilitate further concept definition and refinement.

Finally, even though terminal airspace, as well as the interaction between the departure and arrival flows near an airport, is often stated as being an exceedingly low-level concern for a system wide investigation, it is often described as a bottleneck that causes delay propagation in other (e.g., ground or airspace) resources. Therefore, more realistic simulation capabilities that differentiate between the en route and terminal environments, while at the same time capture the interaction between the two environments, are needed for higher-fidelity simulations and assessments.

4.3 Section 3 – Flight Schedule and Trajectories

4.3.1 Section Description

The Flight Schedule and Trajectories Section of the questionnaire and associated interview focused on fast-time modeling capabilities related to 4D flight trajectories; the Section covered questions about flight plan specification, the type of inputs used for flight schedule and trajectory modeling, and the ability to differentiate between IFR and VFR flights, optimize flight trajectories, model 4D contracts and routing, and model uncertainty in flights' 4D positions.

4.3.2 Current Capabilities

The US tools use Enhanced Traffic Management System (ETMS), National Off-load Program (NOP), Performance Data Analysis and Reporting System (PDARS), Airline Service Quality Performance (ASQP), Aircraft Situation Display to Industry (ASDI) or the Official Airline Guide (OAG) airline schedule data to derive modeled flight trajectories. The European tools usually consider CFMU traffic data, but can accept traffic from other sources, as long as the data is correctly compiled into the traffic input table. Typically, departure and arrival airport information, and scheduled departure times are specified via an input file; most tools also use flight routes specified via inputs such as filed flight plans or as-flown (based on radar data) routes, or are determined as great circle routes or wind optimized great circle routes (not frequent). In addition, some tools are also capable of considering aircraft types, initial cruise levels, cruise speeds, level of equipage and/or tail numbers. However, the notion of tail number is not integrated in most of the tools; several developers explained that this was due to the difficulty of accessing this information.

In most tools, input specified schedules and/or routes are converted into flight trajectories through pre-processing; in some cases this was an external function rather than a built in function. Some tools are capable of optimizing either flight schedules (e.g., by minimizing overall delay) or flight trajectories (e.g., by minimizing flight distance or duration); note that other external pre-processors may be used to enable other flight trajectory optimization methods based on fuel consumption, flight cost and other relevant considerations. Most of the tools then diligently enforce these lateral trajectories, and are capable of changing only flight duration by adding flight delays as necessary; the delays are typically accumulated while the aircraft is still at the departure airport (ground delays) or in en route airspace (airspace delays). Some tools are capable of cancelling flights when their ground delay reaches an intolerable level (specified by inputs).

Finally, a few of the interviewed tools are also capable of considering uncertainty in flight positions. Typically, the uncertainty is modeled as an error in lateral or horizontal position of a flight, and may be associated with the level of equipage on the aircraft; this error is incorporated as a distribution function specified via inputs, and typically requires a significant set-up time and prolongs the scenario run time. For that reason, this capability is rarely used. Another, more often utilized, type of uncertainty is departure time uncertainty; it is most often incorporated through pre-processing and does not significantly affect simulation run time.

In terms of handling international flights, most of the European tools attempt to reproduce the CFMU processes by applying rules for such flights. Only two tools, the ones fully reproducing the CFMU processes, do it automatically.

4.3.3 Gaps and areas of research

The interviews pointed out that no tool was capable of differentiating between IFR and VFR flights in a single run. In fact, differences in behavior, rules and separation standards between different categories of flights or different categories of airspace units cannot be accurately mimicked by the existing modeling capabilities. Even though this issue is less salient for a system wide simulation, it is important to be able to assess propagation of impacts from one system element to another. For instance, transition of IFR flights through VFR flight levels in the vicinity of an airport, or a thorough investigation of the impact of Very Light Jets into system wide operations and performance would require such a capability.

Wind data is rarely used for initial flight trajectory and optimal aircraft routing calculations. It is also important to point out that there are two different sets of wind data that may be beneficial to incorporate into consideration: wind forecasts and actual winds. By investigating the discrepancy between the wind forecast and the actual winds, it would be possible to determine the impact of error in wind prediction onto the predictability of the flown 4D trajectories. Wind forecast data are readily available from several sources and in several degrees of granularity; unfortunately, the same is not true for the actual wind data that is much more difficult to obtain and process.

A 4D contract is an agreement to follow a given 4D trajectory to ensure conformance. Since few tools considered uncertainty in flight positions, 4D-contract capabilities are rarely integrated in the investigated tools. Plans to implement this were identified by some tool developers.

4.4 Section 4 – Separation – Tactical Control

4.4.1 Section Description

The Separation – Tactical Control section of the questionnaire and associated interview focused on the fast-time modeling capabilities related to ATC activities that monitor and separate airborne flights from other nearby flights and/or severe weather cells. The section covers questions about the types of separation standards used by the tool (e.g., lateral, longitudinal, vertical separations for aircraft to aircraft, aircraft to airspace), conflict detection and resolution capabilities by domain, the ability to model separation standards as a function of the level of onboard equipage, and re-routing capabilities in response to severe weather or traffic congestion.

4.4.2 Current Capabilities

There are three types of capabilities used to determine changes in flight trajectories that enable a model to mimic ATC responses to traffic and/or severe weather related events: (1) detecting and resolving airborne conflicts between flights, (2) determining re-routes around severe weather cells, and (3) managing capacity and demand imbalances.

Typically, aircraft-to-aircraft conflicts are resolved by implementing small deviations in speed, altitude or the lateral trajectory that ensure conflict-free resolutions from other nearby flights. Re-routes around severe weather cells are, on the other hand, resolved by implementing larger deviations, as necessary, to avoid severe weather impacted regions; these solutions may be limited by the existing waypoints or route structure, but could also be produced for a generic or hypothetical airspace (e.g., by using only latitude, longitude and altitude information). There are several different approaches used to determine re-routes: (1) by substituting the affected routes with appropriate National Playbook routes or European re-routing scenarios; (2) by performing a minimum heading deviation search or a minimum path search to determine the best re-route around severe weather cells; (3) by optimizing changes to all flights, including the ground delays, flight cancellations, and pre- and post-departure re-routing. Finally, managing capacity and demand imbalances typically utilizes delay as a control mechanism, and may involve both ground and en route/airspace delays.

Due to potential conflicting solutions produced by these three capabilities, most tools can use only one of the three capabilities at the same time; a majority of the tools only have the capability to manage capacity and demand imbalances or to determine re-routes around severe weather cells. In fact, a conflict detection and resolution capability was found in only two of the US tools, and in five of the European ones; one of the two US tools was actually found capable of determining re-routes around weather that were also conflict free from other nearby flights, while the other US tool could only use one of the three trajectory modification capabilities during a single run.

In addition, only one of the investigated US tools was capable of considering controller workload and tasking as a potential limit to sector capacity. This tool did determine separation violations, but did not attempt to resolve them; it simply accounted for the complexity of the situation, determined its impact on controller workload, and adjusted aircraft flows into the sector to prevent sector overloading.

The capability to investigate the impact of turbulence in the en route environment was not found in the surveyed tools. However, the participants indicated that if an affected region could be defined, then aircraft could maneuver around this region similarly to moving around a severe weather cell. The Pilot Reports (PIREPS) system could be used to provide this information.

Finally, most of the tools modify trajectories or make speed adjustments based on winds during pre-processing. However, modifying trajectories for optimization is uncommon.

4.4.3 Gaps and areas of research

Some of the capabilities used to determine changes in flight trajectories that mimic ATC responses to traffic or severe weather related events are still not developed to the desired level of fidelity. For instance, not all of the restrictions affecting potential flight trajectory modifications can be modeled in a single run of any of the interviewed US tools; a comprehensive set of restrictions includes conflict detection and resolution, re-routing due to moving severe weather cells, and objective capacity related limitations. Furthermore, incorporating the impact of human performance on trajectory modifications simultaneously with the above restrictions will be critical to studying system wide impacts of new operational concepts or technologies within the NextGen and SESAR Programs.

Among the European tools, while nearly half handled aircraft to aircraft separation, only three or four are capable of handling aircraft to terrain / obstacle separation, and aircraft to airspace separation; usually by applying rules. Four of the tools are capable of maintaining separation standards as a function of aircraft equipage. Such a feature will likely prove necessary for the investigation of future concepts.

Up to seven European tools are able to deal with re-routings, but in the majority of the cases this is achieved by applying user pre-defined routes. Only two tools apply re-routing strategies.

4.5 Section 5 – Traffic Flow Management

4.5.1 Section Description

This section discusses the traffic flow management modeling capabilities of the tools. It identifies the extent to which the modeling community can capture planning and coordination actions and simulate specific traffic flow management procedures, ATM functions, in-flight decision making, and restrictions. The capabilities related to severe weather cell modeling were also discussed in this Section.

4.5.2 Current Capabilities

Only a few of the US tools surveyed capture short (on the day of the operation), intermediate (up to six days prior to the day of operation) and long-term (seven days or more prior to the day of operations) planning and coordination actions. However, the question addressing this was viewed as relatively vague and unfortunately did not capture the intended information. Most of the responses indicated that the tool could be used to capture intermediate and long-term planning activities, but only through iterative runs as opposed to automation (e.g., defining routes, sector configurations). Short-term planning and coordination involves re-routing due to traffic/weather situations and can be captured by most tools. Most of the European tools are capable of capturing long-term, medium-term, short-term and immediate planning, but in most cases this is done by users pre-processing their own planning actions and providing them to the tool as a static planning input. However, this does not always reproduce the CFMU processes where slot allocation dynamically changes the planning.

Miles and minutes in trail are used to apportion traffic in manageable flows and are an important concept in TFM and should therefore be a requirement for a tool that considers TFM capabilities. Of the US models surveyed, three had no or limited ability to model miles or minutes in trail. The remainder of the models primarily supported minutes in trail; specifically, aircraft to aircraft separation, airports (based on origin or destination), altitude, sectors, fixes and routes. The models capable of imposing miles in trail restrictions focused on fix, airport and aircraft to aircraft separation. Of the European tools surveyed, five are able to implement miles and/or minutes in trail, mostly by using aircraft to aircraft separation measures. Three can focus on fix, airports (based on origin and destination), sector and route; only one can focus on altitude.

Another important concept in TFM is the ability to meter or sequence aircraft. Time-based metering is a method to manage high volumes of traffic by scheduling arrival or departure aircraft at specific locations (i.e., fixes and runways). In Europe, only four tools handle time-based metering. Two of the US tools surveyed model time-based metering to some extent; one allowed arrival fixes to be setup as queues to meter aircraft. The other provides a capability to model a function similar to the Traffic Management Advisor – Multi-Center TMA-MC. It uses an algorithm that looks at both the local facility and adjacent facility airspace to maintain capacity constraints. Therefore, it performs the metering in a more global sense as opposed to a specific TFM tool which is specific to a certain local area.

Sequencing is used to achieve spacing between aircraft and is typically used to create a constant flow at a fix or airport. The US tools surveyed are limited in their ability to meter or sequence traffic. The three US tools that provide the capability primarily use fix points for arrival and departure sequencing; en route sequencing is accomplished by adjusting departure times. Of the European tools five can deal with arrival and departure sequencing.

In the US, terminal and en route holding is not directly simulated by most tools. The one tool that does model holding does it via first-in-first-out queues. A few of the European tools have the capability to model both terminal and en route holding.

Flight departures are delayed through changes to the flight schedule, Ground Delay Programs (GDP) or queued at the airport during the re-planning process. Ground Stops (GS) or Tactical Departure Slot Allocation, fix balancing and dynamic sectorization are not thoroughly represented in the US tools surveyed. However, one tool in particular simulates GS, GDP, and fix balancing in detail. By comparison, seven of the European tools have a capability to model ground delay programs and slot allocation processes; some of these tools can also model ground stops or tactical departure slot allocation by using pre-specified rules. Fix balancing and dynamic sectorization are also poorly represented.

One US tool considered the entire network of system elements (i.e., airport arrival and departure rates and sector MAP values) in creating a new system-optimized plan; re-planning is possible in both time and space. Three of the US tools model the planning/re-planning process. Flight trajectories can be amended through various mechanisms; including “Playbook” rerouting, Coded Departure Routes (CDR), direct routing, and automated weather avoidance algorithms (these are usually user defined options). Of the three tools, one allowed for amendments during pre-departure only by providing a list of possible routes to the destination. Within two of the models flights can be cancelled and their trajectories swapped. Among the European tools, six model the planning/re-planning process, half of which do so by applying rules (user pre-defined options structured in prioritized rule-bases). Most of them can amend the flight trajectory, the flight departure time, cancel a flight and / or swap trajectories (in these cases, rules and priorities have to be specified as inputs to allow the model to mimic reality, current and/or future operations).

The capabilities related to modeling severe weather cells varied between tools. Many of the US tools considered reducing capacity, airport or sector, based on location of the weather cell. Most of the European tools on the other hand considered the location, shape, and movement of the cells. Aircraft reroutes around weather are covered in Section 4.4.

One of the tools has a unique feature in modeling severe weather; it uses two separate weather models: a forecast and an actual weather model. This tool considers the area of coverage of convective weather as a function of time. Actual weather is represented by a pixel based image that is overlapped with the sector boundaries; the model compares the two areas and estimates the percent of sector that is covered by convective weather and the corresponding decrease in capacity. While forecast weather is represented by a polygon, its impact is determined in the same manner as actual weather. The corresponding decrease in capacity is used from "now" to the time when a new forecast is released. Also, flights can be either diverted or held at the boundary when sector load exceeds capacity.

4.5.3 Gaps and areas of research

Globally, as a confirmation of previous AP9 investigations [2], Traffic Flow Management in system wide modeling simulations has not reached a sufficient level of maturity to support future concept investigations.

Dynamic sectorization, multi-sector planner and 4D trajectories were identified as the three most important new TFM concepts that are the most likely to assessment in the near future; these are likely to be followed by the need to investigate open-loop TFM (i.e., 4D), implementation of the Network Operations Plan (NOP), and the interactions of multiple components of future concepts. [2]

Time-based metering was lacking in many of the tools. New concepts, such as the Traffic Management Advisor (TMA) and MC-TMA, assist the controller by metering or sequencing traffic based on time. Without a time-based metering component the tools will not be able to simulate these concepts.

It was interesting to note that many of the tools in the US can not directly simulate holding either in the terminal or en route areas. Most of the holding was achieved by stopping the aircraft (waiting in the queue) before moving on to the destination airport. Other distinguishing features lacking in the US models but not in European ones were the capability to model Ground Stops, Tactical Departure Slot Allocation, fix balancing, and dynamic sectorization.

None of the surveyed US tools were capable or flexible enough to support modeling of the Multi-Sector Planner (MSP) concept. One European tool appears to be able to simulate MSP; however in this case it is a multi-D-side controller supporting several R-side controllers.

For the most part, airline operations centers (AOCs) are not modeled by the surveyed tools. However certain AOC capabilities can be modeled to some extent. Modeling of flight cancellations can be accomplished through historical data (as inputs based on a previous day of operations), reaching a delay threshold, or the number of flights accommodated by the system based on a tolerable level of delay. The last option considers system capacity levels and will cancel flights if the resource (e.g., airport) reaches a certain delay. This is accomplished as an output metric to the planning process as opposed to a day-to-day operational cancellation. AOC capabilities such as flight cancellations, flight swaps, banking operations, aircraft fueling, flight information, flight plan submission and evaluation, gate scheduling, and gate service times were often modeled during pre-processing. While limited, it does not affect the simulation directly during a run. The one exception was a tool that redistributes flights if an airport capacity is exceeded.

Only one of the tools surveyed modeled non-compliance for ground delay programs and in-trail restrictions. This capability is based on a user-specified probability of adhering to the GDP or in trail restriction.

Only one of the tools has the ability to divert a flight to another airport; however, this function is currently not in use (the logic associated with diverting aircraft was not discussed). This capability may not be used very often; however flight diversion to other airports might be beneficial to investigate in “what-if” scenarios for homeland security and/or specific severe weather impacted flights.

4.6 Section 6 – Airports

4.6.1 Section Description

This section provides a description of the airport operations related modeling capabilities in the system wide tools. Airport (runway) capacity continues to be a significant constraint on the air traffic system. In addition NextGen and SESAR have increased the scope of the system from runway-to-runway to gate-to-gate and also curb-to-curb or door-to-door. [3, 4, 5] The scope of the TIM and discussion of system wide models in this document has been defined as gate to gate.

4.6.2 Current Capabilities

All the US tools surveyed have some representation of the airport. Most of the tools simulated airports as queues with associated arrival and departure capacities. This is reasonable since most capacity constraints are associated in some way with runways. Where airport capacities are involved most of the tools relied on Pareto frontier curves to determine the arrival and departure runway capacities. A few of the surveyed models represented an airport in detail; these may include such features as:

- Taxiway usage – modeling aircraft movement from gate to runway and runway to gate including travel time and the delay associated with congested taxi routes.

- Gate usage – modeling individual gate locations for aircraft, including delays at gates due to aircraft stand saturation or delay at the gate forced by queue saturation at the departure runway, push-back operations and its potential interference with taxi routes.

- Staging areas – modeling areas at the airport to stage aircraft, either arrivals waiting for empty gates or departures sequencing for departure runways.

- Runway characteristics – modeling runway dependencies between arriving and departing aircraft based on runway configuration, intersection takeoffs, crossing points and procedures, and runway occupancy times.

- Ramp and ground control - modeling aircraft arriving to an assigned gate, aircraft departing the gate, and aircraft movement around the gate area.

- Departure sequencing – modeling aircraft sequencing at the departure queue to allow for aircraft with no or limited restrictions to depart before aircraft with restrictions.

Most of the tools surveyed allowed for airport capacity changes based on IFR weather conditions or configuration (runway usage) changes. When demand exceeds capacity, delay is accumulated in either en route airspace for arrivals or on the ground for departures. All the tools took into account at least 60 airports. However, some were capable of modeling thousands of airports simultaneously; in these cases, hardware specifications were identified as the most significant limitation to the upper bound on the number of airports that can be modeled simultaneously in a single run.

Most of the surveyed European tools model airports, but to a varying degree of precision. Four tools provide fully detailed modeling of airport operations (taxiway usage, gate usage, staging areas, runway characteristics, ramp and ground control, departure sequencing). These tools included operations from the initiation of service to the end of the take off roll and from the touchdown point to final service. However, only 3 of the tools can model departure slot times in a manner that realistically emulates the slot allocation procedure. When the airport becomes saturated the five tools can either react by separating on runways, applying delays, allocating slots, implementing ground delays or by user-defined actions.

4.6.3 Gaps and areas of research

As mentioned in section 4.6.1, decision makers are shifting the focus of system-wide observations on the gate-to-gate and curb-to-curb impacts. As indicated, only a few of the tools represented airports with any degree of detail. This is most likely due to one of the following three issues: (1) In most cases the surveyed models are fairly mature and changing them to include a detailed airport representation would be difficult; (2) Adding a detailed airport increases the processing requirements; and (3) Including a detailed gate to gate representation may not be required for a task at hand. The third point is interesting from an analysis standpoint, since even though decision makers may be expanding their focus to include airport operations as well, this may not be always necessary to understand the system wide impact gate to gate in all cases.

Typically, incorporating airport or runway capacity captures most of the delay at an airport. However, what is the impact on the system when a gate is not available or the airport is so congested on the surface that aircraft movement is nearly gridlocked? Similarly, many airport analyses do not consider the impacts of en route congestion onto the airport operations; for instance, can an airport release a departure when a 30 mile in trail restriction is in place on its departure route?. Such impacts of one system resource onto another and the corresponding trade-offs are becoming more and more important to study. A possibility might be to create a detailed airport model that includes the en route environment in less detail that attempts to capture the impact of gate to gate operations. Therefore, depending on either of the questions being asked, or the concept being explored, it may or may not be necessary to include some level detail of airport operations in a system wide tool.

4.7 Section 7 – Aircraft

4.7.1 Section Description

This section provides a description of aircraft performance characteristics included in system wide models. Also, this section addressed the questions relating to the Unmanned Aircraft Systems (UAS) and future aircraft performance characteristics.

4.7.2 Current Capabilities

Each tool handled aircraft performance in a slightly different manner. However, the main focus for most of the tools was the aircraft performance characteristics defined in the Base of Aircraft Data (BADA). According to the website (http://www.eurocontrol.int/eec/public/standard_page/ACE_bada.html, BADA aircraft performance characteristics are based on the Total Energy Model (TEM), which is a reduced point-mass model. TEM equates the rate of work done by forces acting on the aircraft to the rate of increase in potential and kinetic energy. In addition to TEM, BADA contains the Operations Performance Model, which defines the aircraft type, mass, flight envelope, aerodynamics, engine thrust and fuel consumption, and the Airline Procedure Model, which defines the speeds that are to be used during the climb, cruise and descent flight phases. More information can be found in the BADA User Manual [6]. Note: the survey did not include details regarding the particular aspects of BADA that were used in each of the surveyed tools. Some models, typically the queuing tools, did not consider detailed aircraft performance, but treated all aircraft types the same by applying average rates, speeds, etc. Other models, however, were capable of considering very detailed aircraft performance characteristics, including four degrees of freedom, phase of flight, climb/descent rates, acceleration/deceleration rates, altitude, International Organization for Standardization (ISO) atmosphere, and winds.

Most of the tools allowed for multiple aircraft classifications, such as wake turbulence (e.g., Heavy, Large, Small, etc.), International Civil Aviation Organization (ICAO) performance groups (e.g., A, B, C), engine types (e.g., Turboprop, Jet), and aircraft models (e.g., B747, A380). However, almost none of the tools were capable of handling noise chapter classification. Most developers indicated that UAS and new aircraft could be modeled as long as the aircraft performance characteristics and trajectories could be defined.

To simulate aircraft movement, most of the tools associated the aircraft with trajectories built from ETMS, PDARS, CRCT, and/or CFMU. Surprisingly, only a few tools include wind data for the calculation of the aircraft trajectories. ISO atmosphere for aircraft speed calculation is not used in many of the tools.

New technologies associated with aircraft avionics and aircraft equipage, such as Automatic Dependent Surveillance-Broadcast (ADS-B) and Data Communications, may have a direct impact on separation rules, airport and airspace access, and controller workload. To assess the system wide impact of these technologies and the associated changes to operational concepts, the tool must be able to distinguish between varying levels of aircraft equipage. Few of the tools surveyed allow for varying level of aircraft equipage and corresponding differences in performance in a single run.

4.7.3 Gaps and areas of research

Only a few of the tools considered aircraft weights, passenger loads, aircraft avionics, navigation equipage, landing capabilities, and the Flight Management System (FMS). Aircraft weight is critical in fuel burn calculations and is also a requirement when simulating aircraft performance in high-fidelity. While passenger load was found in only one tool (it is usually an airline metric), it directly impacts aircraft weight and therefore aircraft performance characteristics including the desired and possible altitude, speed, and aircraft climb/descent profiles. Aircraft avionics, navigation equipage, landing capabilities, and the FMS are important attributes of an aircraft but are usually only recognized by the tools as a limitation of a resource (i.e. what procedures can an aircraft use based on equipage). With the potential for self-separation operations and technologies such as ADS-B, modeling the aircraft in more detail and its impact to the system will become increasingly important.

As highlighted in other sections of the questionnaire, environmental constraints are not sufficiently implemented in system wide models. Noise chapter classification and other environmental constraints will be required in the near future, since environmental concerns are becoming more stringent each year. These issues are discussed in more detail in section 4.9 of this report.

4.8 Section 8 – Collaborative Decision Making

4.8.1 Section Description

This section discusses the extent to which the tools model CDM. This includes how actors in the system interact with each other and how they affect the system.

4.8.2 Current Capabilities

CDM capabilities were highly limited in the surveyed tools. One tool performed flight slot swapping via pre-processing. Two other tools use software agents as actors to simulate behavior of various system elements; however their coordination is not modeled. The third tool models airline schedule recovery in collaborative flow management with airport and airspace capacity constraints.

4.8.3 Gaps and areas of research

This survey confirmed previous AP9 investigations which indicated CDM capabilities are very rarely implemented in current system wide models. CDM is a rather broad term and covers various aspects of information exchange between actors in the system; however certain areas of CDM could be analyzed relative to their impact on the system. Two examples of this are: (1) CDM between AOC's and TFM; here, the time and resulting decision to coordinate a rerouting option could impact the system as a whole; and (2) CDM between pilots during self-separation; here, a decision could affect other aircraft in the system or airline goals.

4.9 Section 9 – Environment

4.9.1 Section Description

This section provides information on how well the tools consider environmental impacts at a system wide level; this includes the ability to model fuel burn, emissions, and noise.

4.9.2 Current Capabilities

The current environmental capabilities in system wide models are very limited. In most cases, only the fuel burn is considered, and is usually calculated during the post-processing of outputs. Other environmental concerns such as noise and emissions can also be post-processed using other dedicated tools.

4.9.3 Gaps and areas of research

Since most tools do not consider airport operations in detail, de-icing was only considered in a few tools. Across these tools, several deicing elements were addressed; for instance, logic rules to decide when to de-ice, probabilistic distributions of the time to de-ice, and meteorological conditions that require de-icing.

While there are several tools that address emissions, noise and other environmental constraints, none of the surveyed tools included this capability. However, addressing environmental constraints in future system wide models would be valuable, as this issue is likely to become an even larger concern as increased traffic demand evolves.

4.10 Section 10 – Infrastructure

4.10.1 Section Description

This section provides information on modeling infrastructure considerations in a system wide tool. Infrastructure considerations include communications, system workload (e.g., processing capacity and message passing limitations), surveillance coverage, outages, system errors, update rates, NAVAID, GPS, and information flow.

4.10.2 Current Capabilities

The capabilities to model infrastructure related considerations in the surveyed system wide models are relatively non-existent. A few of the surveyed tools provide simple infrastructure and system failure modeling capabilities by adjusting the airport/sector capacity. One of the surveyed tools does have a companion version that considers communications, navigation, and surveillance; however this version was not considered in the interview process.

4.10.3 Gaps and areas of research

The need to simulate infrastructure has been raised by facilities and equipment domain decision makers. However, as with the need to incorporate more detailed airport operations in system wide analysis, it is important to consider how much infrastructure detail should go into a system wide tool. New technologies are being proposed in communications, navigation, and surveillance, and the impact from their potential implementation needs to be investigated from a system wide perspective. Also, before investing in a technology, it is important to understand its ability to handle the requirements of the entire system. One solution may be through an analysis of the effects of various technological solutions on the resources within the system; this could then be applied as a constraint to a given resource by translating it into a tool input for assessing the system wide impact.

Another important infrastructure related analysis question is the impact of failures and outages on the system. This could have a direct impact on a number of important issues, including national security.

Other infrastructure considerations, such as where to place a particular piece of equipment to ensure its intended support of a new procedure or concept, are also emerging as important to study using system wide models.

4.11 Section 11 – Human Performance

4.11.1 Section Description

This section discusses the degree to which human performance is modeled in the surveyed tools; it addresses which aspects of human performance are modeled, including the specific actions and workload components. In addition the roles and/or agents modeled by the tools are identified.

4.11.2 Current Capabilities

Among the US tools, only one tool had the capability to calculate workload by considering typical R-side controller tasks and the corresponding times-on-task. Using this task-allocation method, the workload was effectively translated into time that the controller spends monitoring and controlling each of the flights under his supervision, and then used to limit the number of additional flights that can simultaneously traverse this sector.

Within the European tools, only the radar, planner and multi-sector planner controllers are modeled. Workload was also typically calculated by considering tasks and the corresponding times-on-task; however, some tools determine workload via post-processing as opposed to it being an integral and limiting component of a simulation. Other actors (e.g., pilot, airline dispatcher, AOC's, flow managers, sector configuration manager, and tower controllers) are only represented in an agent-based simulator, and workload models for these actors are not yet fully developed.

4.11.3 Gaps and areas of research

Determining perceptual, cognitive, and motor requirements and exploring augmentation of performance were perceived as too detailed for system wide investigations among both the 2006 TIM and the interview participants. However, mechanisms of performance and prediction of performance were identified as important considerations at a system wide level; for instance, predicting response times to alerts, visual search times, time spent performing conformance monitoring, visual scanning times for various separation standards, the likelihood of blunder recognition and temporal response/recovery to various types of operational scenarios. It was also pointed out that certain mechanisms of human performance could be scaled to demonstrate an effect on system wide operations. These include closed-loop operator loading (e.g., feasibility and recoverability measures) and the requirements for, and effect of, aiding systems (e.g., reduction in demand on an operator and/or the likelihood of, or impact of, an error). None of the corresponding capabilities were identified in the surveyed tools.

4.12 Section 12 –Software

4.12.1 Section Description

This section provides a description of the software and hardware platform supporting each tool, as well as the software architecture and maturity of the tools.

4.12.2 Current Capabilities

The modules or tools are written in a variety of languages. In the US, it's evenly distributed between object oriented and structured languages, while in Europe nearly 65% of the modules or tools are written in an object oriented language. This diversity of programming languages makes the integration of tools difficult.

Most of the tools have an open and modular architecture, but a few appear to be difficult to update.

The ability to accept external calls is an indication that the software is flexible enough to allow for improvements in its capabilities. In this manner, the developer does not have to go through many lines of structured code to add a capability. Only a few of the US surveyed tools had the capability of accepting external calls, while among the European tools, nearly all of them accept external calls.

Most of the European tools use exportable files for all data output. This question has not been directly answered in the survey of US tools.

A high level of tool maturity has been noted for both the US and Europe. Only a few tools are still in development or prototype status.

As far as tool validation is concerned, all of the tools have been validated by comparison to either previously validated applications or actual operational results. Additionally, significant effort has been expended on maturing the tools.

4.12.3 Gaps and areas of research

The main two problems with the existing tools' architecture and software is the difficulty of integration of new capabilities and disconnectivity between the tools. However, Section 3.2 does provide some insight into the advantages of a simulation platform.

5 Summary and Recommendations

The objective of the 2006 AP9 TIM and subsequent questionnaire-based interviews was to: "Identify the current and future state of system wide modeling in fast-time simulation." This was achieved by focusing on information provided by participants at the 2006 AP9 TIM and the interviewed tool developers and users.

The 2006 AP9 TIM provided information on current system wide tools and the needs and requirements of the service providers. This information was then used to develop a questionnaire to facilitate capturing the capabilities that currently exist in system wide tools. On-site and telephone interviews were then conducted with the model developers and users to capture the capabilities of their respective tools and to answer specific questions that would be difficult to address in a standard survey.

It is important to point out that all observations offered in this report are limited to the 18 tools that were surveyed.

5.1 System Wide Modeling Capabilities: Requirements

At the 2006 AP9 TIM and during the subsequent interviews, the issues of the required system wide modeling capabilities were often debated. The main objective of system wide models was identified as supporting trade-off studies and to support decision making. In particular, the following topics of interest were identified:

- Identify bottlenecks in the system,
- Compare technologies,
- Assess integrated effects of concurrent investments in different technologies,
- Evaluate if future concepts can be achieved (feasibility assessments) or should be pursued (benefits assessments),
- Compare future concepts of operations, and
- Identify the issues that need further (high fidelity) investigation.

However, depending on the exact issue being investigated, the fidelity required to truly understand the system wide impacts varies. Traditionally, system wide models have been considered high-level models, and, as such, do not consider details that have only recently started to emerge as important considerations. For instance, the impact of the differences in performance between aircraft models, including their vertical profiles and fuel burn. Different aircraft models will prefer different 4D trajectories between the same airport-pair (as determined by optimizing fuel burn and flight duration); these trajectories are also dependent on the winds en route and the weight of the aircraft. If these differences in performance and preferences in 4D trajectories are not properly identified and dealt with, a system wide model will produce an unrealistic airspace demand scenario. For example, an attempt to investigate and understand the impact of a large influx of Very Light Jets or Unmanned Arial Systems into the NAS will fail if the user behavior is not properly addressed.

Although system wide models do not necessarily need detailed aircraft performance models and sometimes adopt the "average across all" method of investigation, the ability to look into details at specific issues is arising as more and more important for evaluations of new technologies and future concepts. For instance, sometimes it is necessary to evaluate both individual aircraft performance (e.g., fuel burn) and system wide impacts to be able to assess if a new concept is truly feasible and beneficial to the stakeholders. Also, sector capacity may not be exceeded when only flight counts are considered, but various other limitations, including aircraft performance, can negatively impact capacity-demand balance.

Two important areas that require aviation industry participation in system wide model development activities are aircraft performance characteristics (e.g., aircraft manufacturers, air carriers, etc.) and CDM (e.g., air carriers). In order to simulate these areas in any detail industry must share information to accurately depict these areas in higher levels of fidelity than are currently available. To accurately incorporate aircraft performance characteristics and calculate fuel burn, aircraft weight needs to be considered. To accurately simulate CDM (including reroute negotiations), an understanding of airline goals at some level is required.

In addition, the typically assumed simple aircraft count as a limitation to the allowed sector occupancy in system wide modeling is not always sufficient; the geometries of the flown trajectories also matter and conflict-free solutions have to be proved achievable as well. This issue becomes even more critical when rerouting is necessary due to severe weather or high traffic demand; the rerouting solutions should be conflict free, otherwise they may not be valid in the real system.

On the other hand, detailed system wide modeling is generally difficult to achieve due to the requirement of significant computational powers and the associated long run-times. In addition, such models are difficult to calibrate, and the methods of their validation are still being debated.

In addition, most current system wide models do not consider the impact of human performance on system operations and performance. Also, humans are adaptable and react to novel situations in ways that models cannot accurately predict.

Finally, it is important to point out that system wide models are typically based on the assumptions driven by the current system infrastructure, operations and procedures. Considering the fact that some of the studies that need to be performed in support of the NextGen and SESAR programs require different assumptions in terms of infrastructure, operations, and procedures, it is questionable if current models have the flexibility to provide accurate insights into the potential of future concepts and/or technologies. At the same time, it is unrealistic to expect that these models predict all aspects of the future; they simply need to be able to provide directed insights into potential outcomes associated with future concept investigations.

Clearly, a balance between too much and too little detail is needed; a balance that also depends on the issues that are being investigated. Therefore, the focus should be moved to a flexibility requirement: system wide models need to be able to support different levels of fidelity as necessitated by the overall analysis objective. Also, these models should not focus on generating outcomes and data-drilling capabilities, rather their focus should be on facilitating the ingenuity of the analyst and providing novel analytical capabilities while at the same ensuring consistency in modeling. Plug-and-play capabilities, including platform simulations, are recognized as a promising way of accomplishing this goal. As a result, such tools would also support using harmonized models that incorporate the different requirements necessary for the investigation of different objectives; for instance, investment vs. new operational procedure analysis.

5.2 System Wide Modeling Capabilities: Gaps

The interviews conducted with the model developers and users revealed that many of the capabilities necessary to realistically model system wide operations and impacts have already been developed and implemented. Among these are the following capabilities:

- Modeling en route and terminal airspace structure, restrictions and operations, including route or way-point in-trail restrictions and metering;
- Modeling 4D aircraft trajectories, based on aircraft model performance characteristics, winds en route, and filed flight plans, as-flown trajectories or great circle routes;
- Modeling conflict detection and resolution between aircraft, aircraft re-routing around severe weather cells, and capacity-demand imbalances;
- Simplified modeling of the uncertainty in flight positions, typically as an error in lateral or horizontal position of a flight;
- Simplified modeling of the controller workload and tasking as a potential limitation to sector capacity;
- Modeling changes to departure time, slot allocation schemes, ground delay and ground stop programs;
- Modeling airport operations and restrictions, including detailed features such as departure sequencing; runway, taxiway and gate usage; staging areas; and ramp and ground control; and
- Modeling variable levels of aircraft equipage and the resulting differences in performance.

However, due to the differences in the objectives pursued by the different system wide tools, as well as the logic and modeling approach implemented in these tools, the above capabilities neither live in a single tool nor were developed to the same level of fidelity across the interviewed tools. In addition, the following insufficiencies in capabilities were identified:

- Objective sector capacity evaluation as a function of controller workload, traffic complexity, separation standards, and weather conditions;
- More realistic interaction between airports and surrounding airspace, especially the propagation of bottlenecks from one resource to another;

- Ability to distinguish operational and procedural differences in and across domains and airspace segments (en route, terminal, approach, departure, etc.) as well as across different categories of flights (IFR vs. VFR) or within different categories of airspace (performance based airspace);

- Environmental considerations and restrictions, including both noise and emissions, to support trade-off studies;

- More realistic conflict resolution capabilities, based on the applicable separation standards (and, performance and/or equipage based);

- More realistic severe weather avoidance capabilities, based on the severe weather cell shape and movement as well as the nearby sector and route capacity limitations;

- Limitations due to the existing infrastructure and its requirements, system errors, update rates, failures and outages onto system wide operations and performance;

- Incorporation of the stochasticity of the processes and behaviors, including uncertainty in aircraft position as well as the non-compliance with the expected user behavior (e.g., 4D contract and TMI);

- Standardized performance metric indicators and measures collected by the tools to facilitate cross-comparison of the outcomes;

- Optimization capabilities, including both individual trajectory and flow or system wide optimized solutions; and

- More realistic TFM and CDM modeling capabilities (especially the negotiations between the cockpit, ANSP and AOC), including future concepts of operation such as multi sector planning.

As mentioned above, not all capabilities were found in any one tool and some capabilities were found in only a few. However, some of these capabilities should also be examined relative to their ability to provide input to other tools. As described above, simulation platforms and component or agent based software architectures applied to future tools may provide ideas on how to solve the issue of providing integrated modeling capabilities.

5.3 Recommendations

In addition to the above identified insufficiently developed capabilities, the following two issues are recommended for integration in system wide tools:

- Flexible modeling environment to support the ability to model different (new) technologies, concepts and procedures, including airborne self-separation; and

- Individual modeling components that support focusing on an issue of interest to the desired level of fidelity, while enabling a harmonious approach to the investigation of other issues of interest (e.g., to their corresponding desired levels of fidelity).

6 Abbreviations

ABNA	Airspace BottleNeck Analyzer
ACES	Airspace Concepts Evaluation System
ADS-B	Automatic Dependent Surveillance-Broadcast
AENA	Aeropuertos Españoles y Navegación Aérea
ANSP	Air Navigation Service Provider
AOC	Airline Operations Center
AP5	Action Plan 5
AP9	Action Plan 9
API	Application Programming Interface
ASDI	Aircraft Situation Display to Industry
ASQP	Airline Service Quality Performance
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
BADA	Base of Aircraft Data
BR&TE	Boeing Research & Technology Europe
CAASD	Center for Advanced Aviation System Development
CAISS	Common ATM Information State Space
CDM	Collaborative Decision Making
CENA	Centre d'Études de la Navigation Aérienne
CFMU	Central Flow Management Unit
CRCT	Collaborative Routing & Coordination Tools
DFS	Deutsche Flugsicherung GmbH
EAD	Evaluation and Analysis Division
ECIP	European Convergence and Implementation Plan

ERAM	En Route Automation Modernization
ETMS	Enhanced Traffic Management System
FAA	Federal Aviation Administration
FACET	Future ATM Concepts Evaluation Tool
FAP	Future ATM Profile
FMS	Flight Management System
FTS	Fast Time Simulation
GDP	Ground Delay Program
GIS	Geographic Information System
GS	Ground Stop
HITL	Human-in-the-Loop
HQ	Headquarters
ICAO	International Civil Aviation Organization
INECO	Ingeniería y Economía del Transporte SA
JPDO	Joint Planning and Development Office
LAADR	Low Altitude Arrival/Departure Routing
LADP	Local Airport De-icing Plans
LCIP	Local Convergence and Implementation Plan
LMI	Logistics Management Institute
MAP	Monitor Alert Parameter
MSP	Multi Sector Planning
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATS	National Air Traffic Services
NEO	Net Enabled Operations
NextGen	Next Generation Air Transportation System

NFM	National Flow Model
NLR	National Aerospace Laboratory
OCVSD	Operational Concept Validation Strategy Document
OAG	Official Airline Guide
PDARS	Performance Data Analysis and Reporting System
PIREPS	Pilot Reports
PROMAS	Process Management Simulator
R&D	Research and Development
RNAV	Area Navigation
RNP	Required Navigational Performance
SAAM	System for Traffic Assignment and Analysis on a Macroscopic scale
SES	Single European Sky
SID	Standard Instrument Departure
SIM-C	Strategy for Information Management and Collaboration
SJSU	San Jose State University
SME	Subject Matter Experts
STAR	Standard Terminal Arrival Routes
SUA	Special Use Airspace
SWIM	System Wide Information Management
TAAM	Total Airspace and Airport Modeler
TEM	Total Energy Model
TFM	Traffic Flow Management
TIM	Technical Interchange Meeting
TMA	Traffic Management Advisor
TMA-MC	Traffic Management Advisor – Multi-Center
TOPAZ	Traffic Organization and Perturbation AnalyZer

TSSIM	Traffic-Sensitive Sector Impedance Model
UAS	Unmanned Aircraft Systems
UDPP	User Driven Prioritization Process
US	United States
V&V	Verification & Validation
WITI	Weather Impact Traffic Index
XML	Extensible Markup Language

7 Reference Documents

[1] Balci, O. (1998), The Handbook of Simulation, John Wiley & Sons, New York, N.Y.

[2] Schwartz, A., Williams, A., Miguel Dorado-Usero, M., Manchon, S., Robin, H. (2006) Traffic Flow Management (TFM) in Fast-time Simulation: Current and Future TFM Capabilities in Fast-time Simulation, FAA/EUROCONTROL Cooperative R&D Action Plan 5 and Action Plan 9

[3] Joint Planning and Development Office (JPDO), (November 2004), Next Generation Air Transportation System Integrated Plan.

[4] SESAR Definition Phase (SESAR Consortium), (July 2006), Deliverable 1 - Air Transport Framework, The Current Situation.

[5] SESAR Definition Phase (SESAR Consortium), (December 2006), Deliverable 2 - Air Transport Framework, The Performance Target.

[6] Base of Aircraft Data, URL:
http://www.eurocontrol.int/eec/public/standard_page/ACE_bada.html

8 APPENDIX A – System Wide Modeling Questionnaire

The system wide modeling questionnaire that was distributed to tool developers and user is provided in the appendix. Formatting has been changed from a spreadsheet format to document format.

Section 1 - General

1.1 Please provide a short description and primary purpose of your tool, including types of studies the tool was used for. Include any high level objectives (i.e. capacity, safety, environment, etc.) Also please include any unique features:

1.2 What type of model best describes your tool?

- Discrete event simulation model
- Continuous simulation model (time-based)
- Agent based simulation model
- Analytical model
- Other:

1.3 Is your tool Stochastic or Deterministic? If stochastic, what makes it stochastic?

1.4 What types of output does your tool provide? Can the output be easily exported to another program (for example, Excel).

- Detailed log of the simulation
- Reports
- Custom reports
- Animation
- Graphics
- Optimization (please describe):
- Other (please describe):

1.5 What metrics (system performance) does your tool calculate?

- Capacity
- Delay
- Predictability
- Flexibility
- Safety
- Flight efficiency
- Environment
- Workload (Controller)
- Complexity

1.6 Does your tool model delay propagation?

1.7 Does your tool accept external calls from other programs?

1.8 Are there future modifications planned for the tool? If yes, what is the estimated completion date?

Section 2 – Airspace

2.1 How does your tool model the en route environment? Does your model consider airspace sectors?

- Considers the shape and the geographic location of each of the sectors
- Consider the altitude band for each of the sectors
- Other, please describe

2.2 Does your tool model the terminal (approach and takeoff) environment?

- as a series of sectors including holding area
- as a series of nodes in a network
- Other, please describe

2.3 Does you tool handle approach procedures? If so, please describe.

2.4 Does you tool handle departure procedures? If so, please describe.

2.5 Does your tool consider sector capacity? Do you use the MAP values to do this?

- 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

2.6 Does your tool evaluate Sector demand against sector capacity? What actions does it take when demand exceeds capacity? (Re-routes, holding-where, etc?

2.7 Does your tool consider Special Use Airspace?

- Considers the shape and the geographic location of Special Use Airspace?
- Considers the altitude band reserved for Special Use Airspace?
- Other, please describe

2.8 Can the characteristics of an SUA change during a run (for instance, on/off status, etc.)?

2.9 Does your tool handle altitude restrictions? If so, how?

2.10 Does your tool handle performance-based airspace (i.e. the notion that flights cannot enter certain airspace unless they are "properly equipped"?

2.11 Can you tool dynamically change the airspace boundaries as a function of time and/or aircraft density?

2.12 Can you tool handle alternative airspace boundaries/structures other than sectors (i.e. hexagonal grids)?

Section 3 – Flight Schedule & Trajectories

3.1 What type of inputs do you use for your flight schedules? (Please check all that apply)

- OAG schedules
- ETMS

- PDARS
- Other(s), please list:

3.2 What fields are included in the flight plan?

- Departure time
- Arrival time
- Route (including waypoints)
- Aircraft type
- Flight level requested
- Arrival airport
- Departure airport
- Equipage
- Tail Number - Does it provide connectivity from one flight to another?
- Other(s), please list:

3.3 How many flights can your tool realistically model?

3.4 Does your tool handle flights that arrive and depart from the same airport (i.e. sight-seeing, training, UAVs)?

3.5 Does your tool handle both VFR and IFR flights? If so, what is the difference in the way you handle them?

3.6 Does your tool handle international flights differently? If so, in what way?

3.7 Does your tool properly handle flights overflying the NAS (i.e. Canada to Mexico)?

3.8 How does your tool model aircraft routes? (Please check all that apply)

- as a series of waypoints (3-dimensional) (based on aircraft performance)
- as a series of links and nodes (discrete event)
- as a series of points/resources with queues at those resources

3.9 Are the initial flight trajectories obtained or modeled as one of the following?

- Flight plan filed route for each of the flights
- Great circle routes
- Wind optimized great circle routes
- As flown based on radar data
- Other, please describe:

3.10 Does your tool calculate optimal aircraft routing; based on:

- wind
- great circle
- Calculates aircraft re-routing around special use airspace
- Calculates aircraft re-routing around moving weather cells
- Calculates aircraft re-routing around conflicts

Other(s), please list:

3.11 Does your tool model 4D contracts/Routing?

3.12 Does your tool consider uncertainty in flights' 4D positions?

3.13 Please list the factors used to determine uncertainty:

Section 4 – Separation – Tactical Control

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

4.2 Does the tool model (please check all that apply):

- aircraft to aircraft longitudinal seperation standards
- aircraft to aircraft lateral seperation standards
- aircraft to aircraft vertical seperation standards
- aircraft to terrain/obstacle separation assurance
- aircraft to airspace separation assurance

4.3 Where does the tool implement separation standards?

- final approach
- take-off
- departure
- cruise
- descent
- oceanic en route
- domestic en route
- terminal
- airport
- landing

4.4 Does your tool distinguish and implement separation standards as a function of aircraft equipage?

4.5 Does your tool use specific rerouting strategies at a local (sector) level in response to weather or to alleviate traffic congestion? If so, how is it performed?

- the tool implements the initiative specified by the input parameters by individual flights
- the tool implements the initiative specified by the input parameters by a given category of flights (departures from a specified airport, arrivals to a specified airport, specified type of flights such as scheduled, cargo, GA, etc.)
- the tool chooses the most appropriate initiative based on the current traffic situation and implements the initiative before take-off
- the tool chooses the most appropriate initiative based on the current traffic situation and implements the initiative in-flight
- the tool chooses the most appropriate initiative based on the forecasted traffic situation and implements the initiative before take-off
- the tool chooses the most appropriate initiative based on the forecasted traffic situation and implements the initiative in-flight

4.6 What type of rerouting/routing at a local (sector) level does your tool perform?

- 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 - User Preferred Tracks
- Oceanic Routing - Fixed Tracks

4.7 Please list additional rerouting strategies, initiatives or tool logic not included in previous question.

4.8 Does your tool perform conflict detection and resolution?

- Conflict detection
- Conflict resolution is based on mathematical equations (algorithmic)
- Conflict resolution is based on a set of rules
- Conflict resolution is based on human performance and interaction
- Conflict resolution is based on delay (resolves conflicts by delaying aircraft)
- Aircraft conflict resolution is based on aircraft pairs
- Aircraft conflict resolution is based on complex algorithms that allow for multiple aircraft resolution

Section 5 – Traffic Flow Management

5.1 In the context of TFM, what type of planning and coordinating actions does your tool capture?

- Long-term, seven days or more prior to the day of operations
- Medium-term, up to six days prior to the day of operation
- Short-term, on the day of the operation
- Immediate, 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)

5.2 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:

- Separation (aircraft to aircraft)
- Airport (based on Origin)
- Airport (based on Destination)
- Fix
- Altitude
- Sector
- Route
- Other (please describe)

5.3 Does your tool provide for time-based metering?

5.4 Does your tool model (Please check all that applies and describe.):
- Arrival Sequencing
- Departure Sequencing
- En Route Sequencing
- Metering or sequencing
- Aircraft Holding - Terminal
- Aircraft Holding - En Route
- Ground Delay Programs/Slot Allocation
- Ground Stops or Tactical Departure Slot Allocation
- Fix Balancing
- Dynamic Sectorization

5.5 Does your tool model Multi-Sector Planning? (Please describe)
- Multi-D-side controller supporting several R-side controllers?
- Local TFM controller or as part of a global/network TFM team

5.6 Does your tool model Airline Operations Centers or the aspects of AOC operations? If yes, what aspects of the AOCs does it model and how is it performed?
- Airline priorities
- Cancellation of flights
- Flight or slot swaps
- Banking operations
- Boarding/unloading procedures (times)
- Aircraft fueling
- Flight information
- Flight plan submission and evaluation
- Gate scheduling
- Gate service times
- Other:

5.7 Does your tool model Non-compliance with TFM Initiative? If yes, please explain the actions the tool takes in cases of non-compliance.

5.8 Does your tool model Diversions to other airports? If yes, does it also allow for the recovery back to its original airport?

5.9 Does your tool model departure release delay?

5.10 Does your tool support any of the following ATM functions?
- Flow control and delay
- Flight data management
- Strategic weather information

5.11 Does your tool model a (re-)planning process?
- Can flight trajectory be amended as a result of this (re-)planning process?
- Can flight departure time be amended as a result of this (re-) planning process?
- Can a flight be cancelled as a result of (re-)planning process?
- Can flights swap trajectories as a part of (re-)planning process (so, for instance, a more important flight obtains better trajectory)?

5.12 Does your tool model in-flight decision making?
- What is the look-ahead horizon for the in-flight decision making?

- Is this a user defined input?
- How does such planning affect other TFM initiatives in your tool?

Section 6 - Airports

6.1 Does your tool model airports?
- 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

6.2 If the airport is simulated in detail; what aspects does your tool simulate?
- Runway usage: Exit probabilities
- Runway usage: Intersection takeoffs
- Runway usage: Runway occupancy times (landing rolls/takeoff rolls)
- Runway usage: Runway dependencies
- Taxiway usage
- Staging areas
- Gate usage: sources and sinks
- Gate usage: individual gates
- De-icing areas
- Ramp and ground control
- Departure queuing (sequencing and capacity)
- Departure sequencing and departure pad capacity
- Departure slot times

6.3 How does your tool determine airport capacity?
- 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 [deterministic airport acceptance rate/airport departure rate]
- Other, please describe

6.4 How does your tool handle airport capacity changes as weather conditions change?

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

6.6 Does your tool evaluate airport demand against airport capacity? What actions does it take when demand exceeds capacity?

6.7 Can your tool model Airport configuration changes?

Section 7 - Aircraft

7.1 How is Aircraft Performance Modeled?
- Uses look up table(s) for Aircraft performance
- Calculates Aircraft performance
- Uses wind data in trajectory calculation

7.2 The tool uses realistic aircraft performance features including:
- acceleration and deceleration
- range of aircraft
- aircraft speeds for all phases of flight
- Other (Describe):

7.3 How many different aircraft classifications can your tool model?
- Wake turbulence (Heavy, Large, Small …)
- ICAO performance groups (A, B, C …)
- Engine types (turboprop, jet …)
- Noise chapter classification
- Aircraft models
- Other, please describe:

7.4 Does your tool determine aircraft speeds by considering:
- Phase of flight
- Range of climb/descent rates
- Range acceleration/deceleration rates
- Altitude
- ISO atmosphere
- Winds
- Other, please describe

7.5 Are there any other aircraft performance related capabilities about your tool you would like to emphasize?
- Aircraft Weight
- Aircraft Passenger Load
- Aircraft avionics
- Navigation equipage
- Landing capabilities
- Aircraft flight management systems
- Other:

7.6 Does your tool handle Uninhabited Aerial Vehicles (UAVs)?

7.7 Is your tool capable of handling future aircraft whose performance has not yet been fully specified (e.g. A380, B787)?

Section 8 – Collaborative Decision Making

8.1 Does your tool model Collaborative Decision Making (CDM)?
- The tool models message exchange – information 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:

Section 9 – Environment

9.1 Does your tool determine fuel burn? If so, does it consider the following?
- Aircraft speed
- Altitude
- Wind
- Aircraft Weight
- Other, please describe:

9.2 Does your tool model environmental concerns?
- Emissions
- Noise
- Atmospheric conditions
- Icing
- Wind

9.3 Does your tool model severe weather cells? If so, how?
- 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

9.4 What source of weather data does your tool use to model severe weather cells?
9.5 Does your tool model Local Airport De-icing Plans (LADP)?
9.6 Does your tool modify aircraft trajectories based upon wind?
9.7 Does your tool reroute to avoid turbulent airspace?

Section 10 – Infrastructure

10.1 Does your tool model any of the following features related to infrastructure?
- Communication usage (e.g., bandwidth)
- System workload
- Surveillance coverage
- Outages
- Update rates
- NAVAIDs
- GPS
- only by input specifications (by modeling airport closures, or GS for instance), but not as a part of modeling logic and not dynamically)

10.2 Does your tool model system failures or errors?
10.3 Does your tool model information flow, such as flight progress strips?

Section 11 – Human Performance

11.1 Does your tool model the communications between the following actors?
- Pilot and Controller
- Controller and Traffic Manager
- Traffic Manager and Dispatcher/AOC

- Dispatcher/AOC and Pilot

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

- R side controller
- D side controller
- Combined R&D side controllers
- Pilots
- Local Traffic Manager
- Global/network traffic manager

11.3 What aspects of Human Performance does your model perform?

- Controller teams (planning & executive)
- Traffic Management (or multi sector) controller activities
- Pilot activities (workload)
- Airline dispatcher activities
- Human error

11.4 What Human Performance roles and/or agents are modeled in your tool?

11.5 Are the tasks of the R and D side controllers linked to airspace (sector) operations?

11.6 Does your tool model human performance? Taskload or Workload? (Please Explain)

Section 12 – Software

12.1 What programming language is your tool developed in?

- Structured - Fortran
- Structured - Simscript
- Structured - C
- Structured - Other
- Object Oriented - Java
- Object Oriented - C++
- Object Oriented - Modsim
- Object Oriented - Other

12.2 What operating system(s) does your tool run on?

12.3 Please describe your software architecture; include flexibility (ease of substituting/removing/adding new modules/components/agents etc.

12.4 How easy is it to integrate new capabilities with your tool? Please describe standards, such as API's, Extensible Markup Language (XML), data exchange, etc.

12.5 Please describe the maturity of your model.

- Prototype
- Beta Release
- Release in Production
- Several Consolidated Releases
- Mature (maintenance only)
- Other, Please Describe