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

"Capability Assessment of Various Fast-Time Simulation Models and Tools with Analysis Concerns"

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October, 2004

Acknowledgements

The persons listed below attended the November 2003 technical interchange meeting in Athis-Mons France. This paper is a collection of their ideas, experience, and expertise. The authors thank the attendees for their dedicated involvement and contributions to this effort.

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ATAC Corporation, U.S.A.: Dave Holl
BAE Systems, U.S.A.: Wendy Humbertson
Boeing, U.S.A.: Paul vanTulder
Centre d'Études de la Navigation Aérienne (CENA), France: Frederic Medioni, Yann LeFablec, Jean-Marc Pomeret, Didier Pavet
The CNA Corporation, U.S.A.: Michael Bennett
CSSI Inc., U.S.A.: Stephane Mondoloni
Deutsche Flugsicherung GmbH (DFS), Germany: Michael Morr
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Preston Aviation Solutions, Australia: Paul Kennedy
Sistemi Innovativi per il Controllo del Traffico Aereo (SICTA), Italy: Roberto Caramanica
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Executive Summary

A Technical Interchange Meeting (TIM) entitled "Presentation and Capability Assessment of Various Fast-time Simulation Models" was held in Athis-Mons, France on November 4-6, 2003. The objectives of the TIM were to provide model developers with a forum to present their current and future modeling capabilities, identify and capture existing fast-time modeling capabilities, identify current and future modeling techniques, identify gaps in current fast-time modeling capabilities, and identify sponsoring organizations needs and requirements.

The first step in obtaining these objectives was to develop a survey that gathered information from tool users and tool developers, hereafter referred to as users and developers, on various Air Traffic Management (ATM) functions. The responses to the survey show that the functionalities presented in the surveys are well represented. However, the results do indicate that gaps or areas with few responses need further consideration. These areas include; aircraft routing around moving weather cells, environmental concerns (emissions/noise/icing), enablers (communication, navigation, surveillance, and information flow), human modeling, dynamic aspects, and flow management. Also, there were responses that indicated it would be difficult to add certain capabilities to their tool. These include; environmental concerns (noise/icing), airport surface navigation, enablers (communication, navigation, surveillance, and information flow), human modeling, system errors, and flow management.

The TIM consisted of presentations by the developers and users, followed by discussion. The TIM provided an excellent means to communicate with developers and users in identifying the needs and requirements for future modeling development efforts. The TIM provided incite into some of the needs of the developers and users not captured in the surveys, as well as analysis concerns such as validation, data integrity, standards, and knowledge sharing.

1 Background

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

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

Action Plan 9 (AP9), entitled "Air Traffic Modeling of Operational Concepts" is another action plan. 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 use and development of Fast Time Simulation models.
3) To build upon on-going efforts in the U.S. and Europe to develop modeling capabilities.
4) To support inter-connectivity of models and the use of standard input data for models where appropriate.
5) To promote best practice and lessons learned in the use of Fast Time Simulation models by U.S. and European partners.

A research plan was created to identify activities that would support the meeting of the objectives. Included in this plan were the identification of ATM areas/functions presently covered by analytical or simulation models and the identification of functional needs and potential technical solutions to address these needs. To identify the current functions and needs, a TIM was created to exchange information between practitioners from the U.S. and Europe.

2 U.S./Europe Practitioners' Technical Interchange Meeting, "Presentation and capability assessment of various fast-time simulation models".

The FAA and Centre d'Études de la Navigation Aérienne (CENA) organized the TIM under the guise of AP5 and AP9. The TIM took place in November 2003 in Athis-Mons, France. The objective of the TIM was to discuss and identify current and future fast-time simulation modeling capabilities and to identify the needs of stakeholders.

The TIM participants included 15 practitioners from the U.S. and 17 practitioners from Europe representing expertise in the field of air transportation simulation. The U.S. participants included researchers from the FAA Headquarters, FAA William J. Hughes Technical Center, National Aeronautics and Space Administration (NASA) Ames Research Center, MITRE, METRON, BAE systems, CNA Corporation, ATAC, Boeing, Preston Aviation Solutions, CSSI, San Jose State University, and Engineering & Information Technologies (EIT).

The European participants included researchers from Aeropuertos Españoles y Navegación Aérea (AENA), Deutsche Flugsicherung GmbH (DFS), Sistemi Innovativi per il Controllo del Traffico Aereo (SICTA), Eurocontrol Headquarters, Eurocontrol Research Centre, CENA, ISA Software, National Air Traffic Services (NATS), Nationaal Lucht en Ruimtevaartlaboratorium (NLR), Ingenieria y Economia del Transporte (INECO), and Service du Controle du Trafic Aerien (SCTA).

The participants of the TIM represented both developers and users. The TIM allowed developers and users to exchange information on current capabilities, future capabilities, and needs. The TIM consisted of presentations by developers and users followed by open discussion. A pre-TIM survey was developed and distributed to the developers and users, the results of which were used to obtain information on current and future modeling capabilities. Appendix A provides a copy of the survey. The modeling capabilities and gaps expressed in this document are based on information presented at the TIM and the results of the modeling surveys.

In addition to modeling capabilities, the TIM provided incite into the concerns of the analyst. These concerns included; limitations to the models, data integrity, and knowledge sharing and are presented in section 5 of this document.

3 Current Capabilities Identified by Survey

3.1 Survey Description

A capability survey was developed to provide information on current modeling capabilities and identify the gaps in those capabilities. The survey (see Appendix A) consisted of check boxes used to identify the current capabilities and planned enhancements of each model. The survey was distributed to developers and users of various fast-time simulation models. Results were received for 15 different models, namely AwSim, FACET, HERMES, NARIM, NASPAC, National Flow Model, OPAS, OPGEN, RAMS, Regional Traffic Model, SDAT, SIMMOD, SIMMOD PRO, SIMMOD PLUS, TAAM, and TARGETS (see Appendix B). In some cases, both developers and users completed surveys for the same model, giving a total of 20 surveys. The survey provides a first step into identifying the needs of future models.

3.2 Survey Results (Current Capabilities)

This section provides the results of the survey by ATM functionality. This information is presented in the order as they appear on the survey. The capabilities listed do not describe the capability in detail, only at a rudimentary level. If necessary, interviews or further questioning would provide the details in each area.

- Tool Description [2] – The models surveyed were classified as either Macroscopic (low detail), Mesoscopic (medium level), and/or Microscopic (high detail). The models were also described as either stochastic or deterministic. Most of the models surveyed were either Microscopic or Mesoscopic with a few considered to be Macroscopic. Nearly half the models surveyed could be classified in varying degrees of detail. Most of the models surveyed were stochastic, indicating some type of probability distribution associated with it, although many of these models could be run without the random element. Only two of the surveyed models were considered strictly deterministic.

- Tool Functionalities
  - Aircraft performance with regard to acceleration/deceleration, aircraft range, and aircraft speeds were available in most of the models surveyed. These areas of aircraft performance are basic functions used by many of the surveyed tools.
  - Trajectory Modeling
    - The calculation of aircraft performance, with regard to trajectory modeling, is frequently based on look-up tables rather than arithmetic calculation and often considers wind as part of the calculation. One tool indicated that it could simulate wind data which is incorporated into the aircraft performance calculation.
    - Calculating optimal aircraft routing based on great circle routes was common in many of the tools. Optimal aircraft routing based on wind was found in a third of the surveyed tools. However, another third planned to offer this functionality in the future. Calculating optimal routing is needed

    when Decision Support Tools (DSTs) calculate optimal routes or when Airlines use optimal routing in their flight plans.

    - Calculating aircraft re-routing around special use airspace (SUA) and to resolve conflicts is available in many of the tools. Re-routes around moving weather cells is not as common among the surveyed tools, although a third planned to offer this function in the future. One tool optimized aircraft reroutes based on the minimum distance around an SUA.

    - Most surveyed tools modeled aircraft routes as a series of 3D waypoints. Other tools simulate aircraft movement by using a link/node structure (discrete event) or a series of points/resources using queues at those resources.

- Environment

    - Nearly all the tools can or plan to model SUA. Those that do model SUA have the capability to calculate re-routes around the SUA.

    - Only a few of the tools surveyed modeled moving weather cells, which confirms the finding that only a few tools modeled re-routes around moving weather cells.

    - Calculating aircraft emissions and noise levels is mostly accomplished in post-processing.

    - Some of the tools surveyed calculated fuel burn, while others planned an enhancement in this area.

    - A few tools surveyed modeled icing, however only as a partial function. Many of the responses indicated that it would be difficult to incorporate this functionality.

- Domain (en route, airport, terminal)

    - Many of the surveyed tools model the En Route environment, either fully or partially and allow for aircraft movement through sectors including handoffs. Based on the survey results, the movement is typically through a series of 3D waypoints. A few of the tools modeled the En Route environment as a series of nodes in a network.

    - Most of the surveyed tools model the Terminal environment (approach and takeoff) either fully or partially and allow for aircraft movement through sectors including holding areas. Some tools represent the Terminal area as a series of nodes in a network.

    - It has been sited that airport modeling is currently the most mature area of ATM modeling mainly due to its large user community [2].

Approximately half of the tools surveyed have or are developing an airport capability.

    - Slightly less than half the tools surveyed included full or partial runway functionality. Only a few of the tools surveyed included detailed runway functionality such as exit probabilities, intersection takeoffs, runway occupancy times (landing/takeoff rolls), and runway dependencies.
    - Most of the tools surveyed focus on the En Route environment. Therefore less than a quarter of the tools surveyed modeled taxiways. This included such functionality as assigned taxi paths, optimized taxi paths, aircraft size constraints, and aircraft blocking. Slightly less than half the tools surveyed indicated it would be difficult to add such functionality.
    - Modeling surface navigation, such as lights and signs, was only available in one tool and a planned enhancement in another. Many of the tools surveyed indicated it would be difficult to add such functionality.
    - The ability to model staging areas, gates (sinks or individual), de-icing areas, and ramp and ground control were only found in a few of the tools surveyed. Many of the tools indicated that it would be difficult to add these functionalities.
    - Departure queuing features, including sequencing and departure slot times are only available in a few of the tools surveyed.

- Most of the tools surveyed indicated that modeling enablers (communications, surveillance, navigation, and information flow) would be a difficult function to add. However, a few tools did indicate some functionality in those areas.
  - A few tools showed a partial capability of communication usage (e.g. bandwidth) for human workload. Even fewer tools showed the capability for system workload or aircraft avionics.
  - Very few of the tools surveyed included the functionality of surveillance coverage, including update rates and surveillance equipment outages.
  - A few of the survey tools included the functionality of navigation equipage, such as Navigational Aids (NAVAIDs). Very few included navigational equipage such as landing capabilities, Global Positioning Systems (GPS), aircraft flight management systems, or aircraft avionics.
  - Information flow (such as flight progress strips) was another functionality lacking in the tools surveyed. One tool indicated the ability to analyze beacon codes for tracking aircraft and another Air Navigation (RNAV) equipage.

- All of the tools surveyed calculate a wide range of metrics. If the tool doesn't provide a metric directly, the survey indicated that a post-processor was available to provide that metric. Metrics are output in multiple formats including simulation logs, standard and custom reports, animation, and Graphical User Interface post-processing.

    - Many of the tools surveyed included full or partial calculations in aircraft throughput, aircraft flight/travel time, aircraft delay (by airport, by fix, by sector), instantaneous aircraft count (for sectors, for terminal area, for airports), planned vs. actual times, planned vs. actual miles traveled, and number of operations.

    - Only a few of the tools surveyed calculated aircraft cancellations and gate utilization. Both these calculations relate to Airline Operations Center (AOC) functions.

    - About one third of the tools surveyed calculated aircraft holds.

    - About half the tools surveyed calculate miles in trail at runways and fixes.

    - A metric found in less than a third of the tools surveyed was the number of aircraft delayed per phase of flight.

    - The number of aircraft during peak traffic periods and the number of aircraft handled per sector was found in less than half the tools surveyed.

    - Few of the tools surveyed handled airport metrics such as; the number of aircraft held in penalty boxes (areas on airport where aircraft must wait), number of runway assignment changes, differences between actual and scheduled push back times, and number of gate reassignments.

    - About half the tools surveyed calculated types of conflicts detected in all phases of flight and the types of conflicts resolved and how.

    - Deviations or changes to the initial flight plan, indicates that the tool can modify the flight plan during the simulation. The number of aircraft deviations, clearances per aircraft, and clearance modifications per aircraft were only found in about a third of the tools surveyed.

    - Runway incursion assumes some type of error or separation violation. Only one tool surveyed partially accounted for this functionality and many of the tools surveyed found this functionality difficult to add.

    - The number of operational errors, both system and actors, was not found in any of the tools surveyed.

    - The number of point outs (see section 4 for a more detailed discussion of point outs), were not found in any of the tools surveyed.

    - The number of handoffs was found in less than half the tools surveyed.

- The modeling of human performance is lacking according to the tools surveyed. Only a few of the tools surveyed accounted for controller teams, traffic management activities, pilot workload, airline dispatcher workload, and human error. Very few of the tools surveyed plan on adding these functions and many of the tools surveyed find it difficult to add these functions.

- Modeling

    - Almost all of the tools surveyed provided detailed logs of the simulation and output reports. Only a third of the tools surveyed provided custom output reports.

    - Less than half the tools surveyed allowed for some type of user interaction. Almost half indicated that it would be difficult to add this functionality.

    - Most of the tools surveyed indicated they could model new aircraft types.

    - Many of the tools surveyed include an input pre-processor, output post-processor animation, and output post-processor reporting system.

    - Many of the tools surveyed allow for probability distributions; however the survey did not go into detail as to the type of distribution or what it was applied to (separations, arrival distribution, etc.).

    - Optimization routines were only available in a few of the tools surveyed. These routines included taxi path routing and cruise altitude calculations.

    - Dynamic aspects such as resectorization and airport configuration changes were found in a few of the tools surveyed. Restratification had limited availability, although a few tools were planning enhancements with this functionality. System failures and system errors were not available in any of the tools surveyed, however a few tools planned to add this functionality.

    - To gain some insight into the tools themselves, the survey requested the programming code that each tool was developed in. 93% of the tools surveyed use object oriented code (JAVA, C++, etc.) or a combination object oriented and structured code. Only 7% were purely structural coded programs.

    - About half the tools surveyed can accept external calls. The trend toward modularization and external interaction has been on the rise and continues to increase. This capability provides the users with the capabilities they need for analysis and the developers the ease of providing additional capabilities without extensive coding.

- Few of the tools surveyed took into account Traffic Flow Management (TFM) functions. Nearly half the tools surveyed indicated that adding TFM functions would be difficult.

    - With regard to AOC's, few of the tools surveyed accounted for flight cancellations, banking operations, boarding/unloading procedures, flight information, and gate scheduling. Slightly more did take into account airline priorities, gate service times, and schedule information. None of the tools surveyed took into account aircraft fuelling; however a few indicated that an enhancement to their tool is planned.

    - Very few of the tools surveyed accounted for ATM functions such as flight plan submission and evaluation, flow control and delay advisory, flight day management, and strategic weather information. About half the tools surveyed indicated it would be difficult to add that functionality to their tool.

- Separation Assurance

    - An aircraft to aircraft separation assurance capability was found in most of the tools surveyed. It was not found in some of the macroscopic tools, although a few of the responses indicated this function will be added in the future. Note: the survey did not address how the aircraft were separated (distance or time based).

    - Very few of the tools surveyed accounted for aircraft to terrain/obstacle separation assurance. In fact, the few that did account for it indicated it was only a partial function. However, a third of the tools surveyed expect to add this functionality. Nearly half the tools surveyed indicated it would be a difficult function to add.

    - Aircraft to airspace separation assurance is found in nearly half the tools surveyed. A third indicated it would be difficult to add this functionality.

- Conflict Detection and Resolution – Most of the tools surveyed have some type of conflict detection, which is required for aircraft to aircraft separation assurance. A little over half the tools surveyed accounted for conflict resolution. Most of these tools based their resolution on a resolution rule base as opposed to algorithms. Very few of the tools surveyed allowed for interaction with the model to solve conflicts and none of the tools surveyed anticipated adding this functionality. Nearly half the tools surveyed based their conflict resolution on aircraft pairs as opposed to complex algorithms that allow for multiple aircraft conflict resolution. Many of the tools surveyed indicated it would be difficult to add a multiple aircraft conflict resolution function.

- The survey provided space to input functionalities not specifically covered in the survey. Below is a list of those functionalities:

    - Sequencing in the terminal airspace

- Scripting language to augment or supplant algorithms within the tool
- Airspace restrictions
- Dynamic capacity reduction based on weather
- Ability to design procedures and design airspace
- System command representation

4 Modeling Gaps Assessment Discussion

The primary purpose of the TIM was to identify gaps in ATM tools and to identify the future needs of developers, users, and stakeholders. This section will present the modeling gaps and future needs that were identified based on survey results and presentations at the TIM. The gaps identified based on survey results are those areas that showed little to no functionality among the tools surveyed. Many of the gaps have also been identified at the Aviation Modeling and Simulation Needs and Requirements workshop held at Volpe in 1999 and presented in the Massachusetts Institute of Technology (MIT) report entitled "Existing and Required Modeling Capabilities for Evaluating ATM Systems and Concepts", March 1997 [2].

This report is an attempt to capture the modeling gaps and needs so that developers have a guideline for future developments. The section is organized into ATM areas similar to those found in the survey for easier navigation through the document.

4.1 Aircraft Performance

Modeling an aircraft using a fast-time simulation can range from an entity in a queuing model with aircraft speed and aircraft size parameters to highly detailed representations with individual aircraft configurations and 6 degrees of freedom. Obviously, the required level of aircraft performance depends on the study and model requirements. An airport model may only require speed and size parameters represented by aircraft classes. A trajectory model would require additional detail such as climb and descent rates, while a noise model could require a higher level of detail with different aircraft configurations (flaps, gears, etc.). Participants from the TIM indicated that modeling very realistic aircraft behavior is needed.

As previously stated, each level of aircraft performance depends on the type of study and how the model is used, however a common problem is the lack of aircraft performance data and standards. Aircraft performance can also be a function of airline operating procedures and destination airport (fuel weight). Solving this problem can be difficult; aircraft manufacturers consider much of the data required proprietary. One source of aircraft performance data is Base of Aircraft Data (BADA), maintained and developed by Eurocontrol. Although the data currently contains 267 aircraft, only 87 are directly supported with the remainder considered "equivalent" types. Until a common source of aircraft performance data is established, researchers will continue to struggle with obtaining validated aircraft performance data. This makes it difficult to compare model results.

4.2 Trajectory Modeling and Rerouting

Trajectory modeling should allow for adjustments to aircraft trajectories based on the current state of the airspace. Given the dynamic nature of the airspace, trajectory modeling also needs to be dynamic. Perturbations to the airspace, such as convective weather, conflicts, and congested sectors affect the flight path of an aircraft. A few tools have the ability to automatically detect and resolve conflicts, however, most do not automatically reroute aircraft based on weather (moving weather cells), air traffic conditions, or strategic flow management.

Trajectory models require aircraft data, flight plan information, site information, and weather data. Where conformance is an issue a track report is also necessary. Conformance to a flight path and trajectory uncertainty has not been modeled. Trajectory models need flight guidance models, wind variability, navigation and surveillance characteristics, and complexity of the path. These and other parameters are currently being evaluated in Europe and the U.S. for a common trajectory algorithm. This algorithm could then be used as a standard for modeling aircraft trajectories, which can evolve conflict detection algorithms.

Dynamic density is a term used to describe a metric that determines the complexity of a sector based on an algorithm. The use of a dynamic density metric could be useful in evaluating the conditions within a sector to determine if a reroute around a sector should be taken. One tool surveyed has a dynamic density feature.

4.3 Environment

Environmental modeling issues, although important, were not specifically addressed at the TIM. However, a need for Physics-based environmental models was identified.

Weather issues can be put into two categories. The first is modeling the impacts due to weather; the other is modeling of actual weather phenomena, such as winds and convective weather to evaluate decision support tools or affects on aircraft. Each category has a different impact depending on the operational environment.

In the En Route environment severe weather impacts the flow of traffic considerably, which causes problems in re-routing the aircraft around the weather cell. Only a few tools allow for routing around affected areas. These tools rely on a depiction of the weather as a "no fly" zone and tend to be stagnant. When running a simulation for a days worth of traffic on a regional or national level, this is unrealistic, since the weather cells move throughout the day. Some tools allow for the "no fly" zone to jump from one location to another during the passing of time. This can be a good work around, however it increases the required input. Also, non-automated re-routing tends to increase the complexity of the inputs by defining many alternative routes. Automatic re-route logic would greatly enhance this capability. Aircraft re-routing around weather also causes an impact on the surrounding areas, which increases the demand to those area thus reducing capacity. Some tools accept pre-processed trajectories that are re-routed around weather cells without consideration of the affect of increasing the demand in some areas. These tools pre-process the trajectories to decrease the processing speed.

In the En Route environment the modeling of convective and/or severe weather along with predicting the path of the weather cell is very processor intensive. Modeling the changing wind speeds and direction during a day would also provide a better representation of the real world. Increasing the level of detail or fidelity increases the processing time and there is a trade off between modeling performance and modeling fidelity. Unless there is a specific requirement for a high fidelity weather model, most users would rather have the performance.

Another area of consideration is turbulence and sudden wind changes, such as micro bursts and wind shear. During flight pilots or AOC's request new flight levels based on the smoothness of the flight. This flexibility in the Air Traffic Control (ATC) system has not been modeled. The weather phenomena known as micro bursts or downdrafts and wind shear have an affect on where or how close an aircraft can fly around severe weather. The ability to model these conditions would allow for the assessment of weather prediction tools.

In the airport environment Instrument Meteorological Conditions (IMC) are usually simulated by increasing aircraft separations, which is adequate for airport capacity analysis. However, there is a need on the airport surface to simulate the pilot's ability to navigate in low visibility conditions, such as fog, and to test tools that help the controller identify the aircraft. Fast-time modeling usually simulates a "perfect actor"; therefore it is difficult to model pilots that can't navigate well or controllers who can't see well in low visibility conditions. Adding stochastic methods to simulate actor behaviors could enhance the simulation; however there is little data to provide an accurate depiction of these behaviors.

Another area of consideration is the need for data. Weather data tied to a certain procedure or airport configuration is limited and in most cases a generalization of Visual Meteorological Conditions (VMC) or IMC conditions is all that's available. If sufficient weather information were made available, the analysis of certain procedures or DST's dependent on weather information would be enhanced.

4.4 Domain

4.4.1 En Route

Modeling the En Route environment has progressed more slowly than airport modeling. The En Route environment can be modeled using a simple link-node structure, but this does not allow for the flexibility that is required for modeling advanced concepts such as free flight. Modeling 4D trajectories with conflict detection, conflict resolution, and dynamic rerouting is very complex and processor intensive. With an increase in processing speeds and the advancements in distributed simulation, the ability to model the En Route environment on a larger scale is becoming a reality.

Two critical shortfalls were identified at the TIM. The first was the ability to model altitude restrictions and the second was the ability to model the appropriate location of delay. Altitude restrictions are procedures used by controllers to allow them to handle more traffic. Altitude restrictions on arrivals result in less fuel-efficient routes for the aircraft and a less than desirable descent profile. Altitude restrictions on departures restrict the ascent of aircraft in reaching cruise altitude. En Route models today do not have the flexibility to impose these restrictions on aircraft. Although some ATM DST's in development plan to eliminate those restrictions, it is still necessary to model the restrictions in order to calculate the benefits of these new tools. En Route models do not have the ability to determine where delay should be taken. Most models apply the delay at the sector level or through TFM initiatives such as a ground or gate hold. With the increase in TFM initiatives and multi-sector planning tools, delay or controller actions could be imposed many sectors before a conflict. In the En Route environment arrival sectors could impose restrictions (delay) to an aircraft in order to sequence the arrivals to an airport. Surveyed tools do not have this capability.

Models have two problems when capturing efficiency in the En Route environment. Queue-based En Route models tend to fly the aircraft too efficiently through a sector without capturing the complexities of conflict resolution and descent/ascent profiles. In practice, controller efficiency is a factor of sector load. Conversely, a controller may allow aircraft to fly direct routes, particularly when demand is low, thus allowing aircraft to have more efficient flight paths. Most models don't allow for this flexibility.

Controllers have the ability to process point-outs, another area of flexibility not captured in today's modeling environment. Point outs are used by Controllers in the U.S. which allow a controller to temporarily "borrow" airspace through coordination with an adjacent controller. This flexibility allows a controller to operate more efficiently. The results of the survey indicate that point outs, are not recorded therefore not simulated. This identifies two needs; 1) The ability to measure a point out (frequency, duration, coordination, task loading) and 2) The ability of the tool to represent the “borrowed” airspace.

4.4.2 Terminal

No one model has been able to capture the complexities associated with the simulation of the Terminal area. Most models represent the Terminal airspace with a strict link-node structure providing little flexibility in rerouting or with a large (almost infinite) capacity value.

Representing the airspace as a link-node structure does provide an adequate representation of the Terminal airspace as it operates today. Usually the airspace around airports provides little flexibility, but as initiatives involving the increase in Terminal airspace evolve, this may not be the case. When represented as a large capacity value it tends to over-emphasize the capacity within the Terminal. Little research has shown what the capacities of a Terminal area should be. One problem is defining an airspace capacity when the aircraft are lined up for final.

Another problem is the decoupling airport constraints from En Route constraints. In practice, constraints at the airport impact the En Route environment and vice versa. For example, decreasing the arrival rate at airports due to weather causes the En Route environment to increase separations thus creating an En Route constraint. Few of the models surveyed provide the ability to link airport to En Route constraints.

4.4.3 Airport

Airport simulation is the most mature of the simulation environments and the tools surveyed have proven invaluable in the assessment of airport improvements. However, these models are limited in evaluating future concepts. The models are based on structured programming techniques and enhancements to them require a fair amount of time and resources.

A problem that was identified at the TIM was the inability of current airport simulations to model paired aircraft approaches. Certain procedures, simultaneous offset instrument approaches (SOIA), for example, require aircraft to land paired in order to maintain separation and increase capacity at the airport, especially under IMC conditions. To assess the benefits of these procedures, the ability to model paired aircraft is required. Some models today do simulate paired aircraft, but not that well.

Another problem identified at the TIM was ground movement procedures, such as movement to and from stands. Aircraft movement has primarily concentrated on taxiway movement, while movement around the gate areas has been somewhat limited.

4.5 Enablers

Enablers are resources in an ATC system that have a certain capacity and when modeled have an impact on the system if that capacity is nearly reached, reached, or exceeded. Few tools model resource loading and those that do don’t provide feedback to the system if the resource is overworked. Identified below are resources identified at the TIM that should be considered.

4.5.1 Workload/Taskload

It must be noted that the term workload in the Human Factors community is different from those involved in ATM modeling. What the ATM modeler describes as workload is really a form of taskload. The issue of human behavior modeling will be addressed in its own section. Few of the tools surveyed calculated taskload and those that did do not have a mechanism to provide feedback to the system. For example, if a controller is involved with a task and a second, more critical task is initiated, the first task will be delayed while the second task is resolved. The system will be impacted based on the delayed first task. A tool with a flexible rule base may handle this situation.

4.5.2 Communication Loading

The ATC system requires communication between many actors and this communication requires hardware and software to run. In many areas communications between aircraft and controllers can be a cause of delay and increase the workload considerably. Without a model that simulates communication loading, this impact is missed.

4.5.3 System Loading

Overloading ATC system components (i.e. increasing the number of aircraft, overloading a sector, testing the processing of certain functions) is an area that requires more research to determine its impact on the system as a whole. Although this is an area that pertains to system testing, determining the impact of an overloaded system provides input into system models increasing the validity of the results of the tool.

4.6 System Performance

Many of the tools surveyed calculated a wide range of system metrics, either through the tool itself or a post-processing application. In most cases the tool provides the metrics based on the functionalities available. Obviously when a tool lacks a certain function, for example the ability to model penalty boxes, runway incursions, operational errors, and point outs; the metric is not provided.

4.7 Human

The ability to model human performance and/or behavior in fast-time simulation has been identified as a problem. A few models do provide detailed workload estimates based on taskload, but do not examine the cognitive issues faced by human participants. These models use decision rules or algorithms to perform taskload analysis. However, future concepts will require the simulation to assess the impact human performance has on systems, for example, the need to model multiple positions (pilot or controller) and the coordination between them. Certain concepts are designed with coordination and collaboration with multiple controllers. With the roles and responsibilities of controllers being redefined being able to model these variations is key.

Experts in modeling, human factors, government, and industry have identified this area of modeling as extremely important and deserving of immediate attention. Any analysis of a proposed concept must consider the human in the design and operation of that concept. Experts have commented that one cannot measure system performance in a system that relies on human performance without considering the human performing within the system. Although this has not been ignored, human-in-the-loop simulation is a way to identify the issues related to human performance, the use of fast-time simulation to access these concepts in the earlier stages of concept development would provide cost savings and a decrease in development times. A cohesive process where real-time workload results could be used as input to fast-time simulations would help improve the human performance measures calculated in fast-time models.

The modeling of human performance is still in its infancy. Research is required in a number of areas concerning human performance models and/or human behavior representations. The research required will range from mathematical representations of human performance to detailed representation. Fast-time simulation usually requires quick turn-around times in processing, mathematical representations would provide fast-time simulation with a more feasible way to evaluate the human within the system; however a "standard" or best way to represent the human is still an area of concern. Research in detailed human representation has been limited, mainly through the Man-Machine Integrated Design Analysis System (MIDAS) model; however research involving software agents may make simulating human behavior more feasible. Areas of research or continued research should include:

- Safety issues, such as low probability events related to human errors
- Modeling of human performance during conflict resolution
- Integration of mathematical models with fast-time operational simulation models
- Integration of detailed human performance models with fast-time operational simulation models
- Software Agents
- Using results of Human-in-the-loop experiments to develop human performance models or to calibrate them

Analysts today are looking toward the human behavior model community to develop validated models of controllers, pilots, and AOC's. The human behavior modeling community has begun to respond with a group research effort.

4.8 Modeling

The TIM and survey also captured gaps in modeling not related to a specific ATM function. Most of these gaps are covered in section 5. One area identified by the survey as lacking is modeling dynamic aspects of the air traffic system. A number of the tools surveyed did account for dynamic runway configuration changes and resectorization, however, none of the tools surveyed accounted for system errors or failures. A few of the tools surveyed have planned enhancements that would include this functionality.

In general, participants felt an open platform and modularization of models would benefit the community by allowing for more flexibility. Modularization makes it possible to easily add or modify components to a model (ex. Conflict resolution algorithms) without modifying the rest of the model. The development community has addressed this and is starting to develop add-ons and modularizing their tools.

4.9 Traffic Flow Management

The ability to model TFM issues has become a concern to aviation analysts. TFM is planning a bigger role in ATM. Many new concepts are geared toward providing system wide flow management.

With this in mind, traffic flow models and/or capabilities are lacking. The ability to model TFM initiatives, control/feedback loops, and interactions with airlines (including cancellations, ground stops, ground delays, etc.) will be essential in modeling an airspace system.

The modeling of AOC's has also become an issue. Questions such as; how do the airlines adjust schedules based on situational information, what is the airline reaction to ground delay programs, and how do they determine cancellations, need answers to determine their feedback to the system and the interaction with ATM. New questions arise when a new concept is put into the system. Mainly, how would the airlines operate under the new concept?

4.10 Separation Assurance

Separation assurance, along with conflict detection, is usually simulated by applying a standard separation minimum between aircraft types, which includes a safety buffer. As new technologies attempt to lower the separation minima, safety becomes a critical issue. Most models in use today can simulate reduced separation and provide predicted benefit of those reduced separations. However, the question remains, can those separations be obtained without sacrificing safety? Another problem facing analysts is simulating mixed equipage of aircraft. Through pre-processing one can develop duplicate aircraft types, one being equipped with a certain technology, the other without and provide separation minima to each. However, questions still remain regarding safety, especially controller reaction and handling of mixed equipped aircraft.

4.11 Conflict Detection and Resolution

As mentioned in Section 3, most of the tools surveyed have some type of conflict detection and over half the tools surveyed accounted for conflict resolution. Most of these tools based their resolution on a resolution rule base. Rule bases can provide analysts with the flexibility to make adjustments to the simulation without having to recode the model. With the exception of a few models, most do not provide rule bases. Practitioners at the TIM agreed that there is a need for flexible rule bases.

5 Analysis Concerns

During the TIM, topics varied from the needs of the tools to the needs of the analysts. The ATM and airport research and development community faces continuous problems analyzing new concepts to improve system performance, since the system is often under change and improvement. The analysts use different models and tools to support their studies, trying to give the most accurate and useful answer to any decision made in the ATM and airports environment. Several problems and concerns are present when studies and analysis are conducted. Areas of concern can be summarized as: recognizing model limitations, improving efficiency of the analysis process, ensuring integrity of data, and promoting effective information sharing.

5.1 Model Limitations

With regard to model limitations, several organizations and experts in the ATM analysis and simulation community have expressed two major concerns:

- No single model meets all the needs.
- Models are not flexible enough to adapt to new scenarios.

The first concern forces research organizations to use and maintain several models, depending on their varying needs. To become more efficient, organizations must integrate the models or develop some type of data exchange software that can produce a best combination of models and provide the best set of results. ATM analysts often use different models that are adapted to the special needs of each study in order to obtain the desired results. Numerous pre- and post -processing software tools are often developed to automate the result process. However, utilizing these models and tools do not necessarily help in increasing the efficiency of the analysis process. The development of data standards, common interfaces, and model/data/tool repositories will help improve the efficiency of ATM analysis.

The second concern relates to the need to incorporate new or legacy functions and scenarios into models, including their impact on all system components. As indicated in the previous sections, many models do not provide the capabilities to access these new functions and scenarios. This results in a need for greater model flexibility to support the analysis needs of any new concept.

5.1.1 Pre/Post-Processing Tools

ATM analysts tend to have several heterogeneous analysis requirements. When using an airport or ATM model, the model usually provides extensive results and data. However, this data might not be the aggregated indicators suitable for the expected analysis. Usually additional calculations, solved by data post processing tools, are needed to get the results from the raw data coming from the model-based tool. The process involves large amounts of data, such as traffic information provided in a given format, which is transformed in order to make it suitable for the model-based tool.

The above idea is valid for most analysis processes involving at least one tool. However, the analysis process usually involves more than one tool or model. So, data processing between tools is an important concern for the analyst.

The ATM analysts also require more complex processors in order to realistically describe their ATM concepts. For example, a trajectory building pre-processor should build aircraft trajectories based on aircraft performances, winds, linkage of flight legs, etc. Such processors are beyond typical file format converters and require additional logic. These tools can be considered complex tools or models themselves. In this way, the need to use processors leads to the need to integrate or link tools and systems, which is addressed in the following section.

5.1.2 Linking of Models

No single model meets all needs; usually several models are used within the same study. The first approach when linking models is the interchanging of data so that output from one model becomes input to a different one. This is quite a common practice and helps the analysts obtain a more complete set of results. This approach is a pure static exchange of data, and is useful when models are used sequentially. For instance, if a scenario has been modeled using a fast time simulator, with sector, flight, route information in electronic format, then to simulate in a real-time environment, the data does not need to be gathered again. It can be exchanged or re-formatted to fit the real time system.

Static exchange of data between models is the most common way of linking models. The ATM research and development community would greatly benefit, however, from a different approach - linking simulators dynamically. Linking Real Time and Fast Time simulations would provide the ability to exchange active flights dynamically from one simulator to another. The ability to model different and customizable hybrid simulation: fast time plus real-time plus analytical would enable very efficient experiments of large areas, where some key aspects are simulated with the human-in-the-loop and the other areas simulated in a virtual world, conducted by model-based or fast time simulators, with real system components and integrated decision support tools. Integrating real system components (e.g. Arrival Manager Tool) into a fast time environment would provide a capability to test the component before operational implementation.

It is clear that dynamic linking of tools would provide important benefits to the ATM research and development community. One problem of such an approach is the need for new model architectures and software development to support such distributed simulation concepts. There is also an Intellectual Property Rights problem for sharing models, in particular when they come from commercial providers.

5.1.3 Optimization

Normally studies conducted by airport and ATM analysts answer "what-if" questions. This means that the analyst is provided with several alternatives for a given change to be modeled and studied, and produces results to decide which alternatives is best from a given set of criteria (e.g., higher capacity or lower delays). The optimization concept means that the analyst is not looking for the best alternative among some pre-defined alternatives, but the optimum solution, whether it is included in the initial set of alternatives or not. So, the result from an optimization analysis might be a completely new alternative.

Currently, there are initiatives in ATM analysis to use optimization as part of some studies. However, optimization requires improvement in the field of linking and integrating tools. A normal optimization process would consist of the following steps:

1. The analyst is provided with input data for different alternatives.
2. Input data is pre-processed and adapted to the type of study and introduced to the model.
3. Simulations are run using, for instance, a model-based tool.
4. Output from the tool is post-processed to obtain desired metrics.
5. Metrics are analyzed.
6. (Normally a "what-if" analysis would end here.) Metrics are then introduced in an optimization function to decide whether to go on with the optimization loop or to stop, given some criteria.
7. If the optimization function indicates that the process is to continue, then input data is changed, following a given criteria.
8. Once the input data is changed, the optimization loops start again.
9. The optimization process is repeated until some metric accomplishes a given optimum criterion. The process is then stopped and the result is the optimum solution.

As can be deduced from the previous “simple optimization process” description, optimization requires a large transfer of data between tools and processors. This process can be done manually once or twice but it is more appropriate for repeating the loop again and again, by an automated process. This would require additional optimization logic and the linking of models and tools in order to be achieved properly.

Furthermore, an optimization platform would require higher flexibility, which would enable the user to substitute functionalities, elements, and/or modules. The reason is that a simulation process might involve several tools and processors, requiring additional effort in software development. If it is designed in a black box, software development would have to be repeated each time the optimization loop changes. Therefore, optimization processes require more flexibility than other types of model linkage.

Besides the previous features, optimization could provide benefit in the design of new technologies. By using optimization loops and given a certain design criteria, optimization could provide the best design as well as the best alternative.

5.2 Data Integrity

There is a growing interest in determining input and output data quality parameters, such as accuracy, uncertainty or reliability, as well as, scenario modeling assumptions and standardization. Issues related to the problems the analyst finds when describing and assessing the quality of data (input and output) and the related implications to reach a common understanding with the decision makers, are described in the following sections.

5.2.1 Assumptions

Assumptions can have a major impact on ATM analysis. Assumptions relate to input data decisions, simulation settings, scenario modeling, etc., which influence the way the model and simulation is to be built. For example, if the assumptions associated with input data are wrong, the results will be wrong, regardless of the quality of the input data.

Assumptions are strongly related to accuracy and uncertainty levels. For example, if a recent traffic sample is simulated, the traffic situation should be realistic with little to no uncertainty. However, to simulate a future scenario, assumptions about the future traffic situation must be made. For this example, the assumptions could change the results completely. Therefore, the results are dependant and sensitive to each assumption. It is very common when forecasting traffic to assume that all traffic grows by a given percentage. Since results are sensitive to traffic assumptions, ATM analysts spend more time developing traffic forecasts for future schedules than most other aspects of the study. Details, including changing from an overall operations count to city-pairs, rolling hubs, real airport capacities, and point-to-point operations, affect the complexity of future schedule development. Another example is defining route settings in the model. Observed delay for a given scenario for a given traffic level can change based on the routing assumed, (e.g., great circles, preferred routes).

Assumptions should also be included in the interpretation of the results. In either case, assumptions should be included in the entire analysis process, as an important part of the methodology. A common validation methodology should address assumptions directly, in order to achieve the expected results.

5.2.2 Traffic and Other Input Data

All input data is important in a model-based study, however, the input quality depends on the available sources. Sectors, runways, taxiways, NAVAIDs, routes, airways, and geometric data are usually provided by the local ATC organization. Control rules and procedures are described in ATC procedural documentation. Aircraft performances are described in aircraft databases, although additional performance gathering is advisable in order to have realistic behavior of aircraft types. When source data is poor or lacking, assumptions and hypotheses have to be made.

Traffic is a key input to any analysis; therefore source data is extremely important. In most studies, future schedules are generated based on present schedule information, therefore assumptions made about the present schedule transfer throughout the developed future schedules.

There is a strong need in the ATM research and development community to create and improve traffic demand generation models in order to have less uncertainty in studies. Results highly depend on the traffic chosen for the study. Accuracy can be gained by basing your assumptions on accurate information and/or by simulating several traffic situations, which would be quite time and effort consuming.

5.2.3 Results

One of the major issues for the ATM analyst is to be able to measure or compare ATM performance in terms of capacity, safety and economics. Recently, security and environmental impacts have been added to the list of performance measures. To measure performance, the ATM research and development community uses fast time simulation, analytical models, risk modeling, and cost-benefit analysis, among other analysis techniques. The final objective is to provide results to decision makers to assist them in choosing the best options to improve ATM.

However, there are concerns on the way results are provided, mainly regarding:

- Validity
- Accuracy
- Reliability
- Utility

Determining the validity of results is the first step to deciding if the results are usable. However, the validity of results is not always clear. Results are not just valid or invalid, but also have an accuracy level, along with a level of confidence. So the analyst can state, for instance, that due to model conditions, input accuracy, and samples size, results are not deterministic, but have an accuracy level (e.g., results can provide average with a given standard deviation) which makes them valid only to a certain confidence level, which is in essence reliability.

There are many statistical methodologies to assist the analyst on how to conduct experiments. They all make extensive use of determining uncertainty-reliability or accuracy-reliability of results, depending on the kind of experiments, associated methodologies, techniques, and even input data and samples. ATM analysts use similar techniques, tools, and inputs to model ATM and run simulations. It is clear that accuracy-reliability information should be part of the data provided by studies, together with results themselves. The major risk comes from the fact that if accuracy and reliability are not provided, it is almost always thought that accuracy is 100% and reliability is 100%. Some initiatives are going in the direction of providing accuracy-reliability, but complexity of tools and diversity of studies made it difficult to be applied in the past. It is a major concern of ATM research and development community to evolve results analysis in this sense.

Dealing with uncertainty is a concern of the ATM analyst. Results can have a large variance depending on input data. This uncertainty must be accounted for by the model and in the design of the analysis exercise. To deal with uncertainty, deterministic models are not appropriate and stochastic calculus must be used. Definition of stochastic variables, identification of optimum number of iterations, statistical understanding of aggregated parameters from iterations results, etcetera, are important issues to be handled by the analyst. It is desirable that models or tools contain enough stochastic calculus features to provide a realistic description of uncertainty.

Regarding utility, it is clear that the objective is to provide valid, accurate and reliable results to decision makers, enabling them to make quick decisions based upon those results. However, the fact that results are valid, accurate, and reliable does not necessarily mean they are useful. When ATM analysts conduct studies, they get as much information as possible, which is good if the results are categorized and used within their field of utility (e.g., particular figures for decision making, aggregated parameters for quick and high level understanding, detailed and extensive description of results for additional information). The goal is to provide decision makers with a clear understanding of the information they need, and provide other information for technical staff, operative staff, and analysts.

In general terms, results need to be clearly classified, and their validity, accuracy, and level of confidence determined in order to make them understandable. However, the variety of data, results, metrics, and models/tools make it difficult to achieve the previous objectives of validity, accuracy, reliability and utility. Standardization, which is addressed in the following section, would clearly assist the ATM analysts with a common metric modeling framework for post processing data, calculating its accuracy and reliability, establishing or agreeing on its validity, and defining its utility.

5.3 Promoting Effective Information Sharing

Information sharing is a common problem within the ATM community. Most studies are performed locally with little data sharing or results sharing. Results presented to the decision makers can often be misinterpreted, resulting in a trust issue with future results. Standards in data and result presentation would greatly improve the analysis process. This section will address the needs for improving the communication between analysts and decision makers and developing standards for a more effective analysis process.

5.3.1 Improving Analyst/Decision Maker Communication

The exchange of information between decision makers and analysts pertains to all aspects of the research activity, from the description of the study to the presentation of results. When describing the study, the problem can be conveyed at too high a level, which is then transferred to the model by the analyst. The model may appear accurate based on the information provided; however it may be representing something different than intended.

When presented with results, decision makers sometime find the information untrustworthy, too extensive, or too detailed. They are required to have faith in the models, which they may not understand. It is the responsibility of the analyst to provide the decision makers with accurate information on the capability of the models and provide results that can be understood. It is the responsibility of the decision maker to provide an accurate description of the requirements and to have a general understanding of the models capabilities in order to trust the results. This will help in solving the problems with information exchange between decision makers and analysts.

5.3.2 Standards

Standards have been identified as a major concern within the analysis process. Many tools, a variety of input formats, heterogeneous metrics and results, and multiple data pre-post-processors are used throughout the world to analyze the same types of systems.

In the following sections, standardization will be addressed, including its advantages and disadvantages to airport and ATM analysis. Knowledge sharing issues will also be explained as a step forward to achieve standardization. Finally, certification and validation approaches will be examined as a step further to obtain standard uses of model based techniques in ATM.

5.3.2.1 Standards in Support of ATM Analysis

One major issue for analysts is the fact that they might have a rich set of inputs and outputs, perform their analysis, and realize they have no standard with which to compare. In this sense, standardization is looking for compatibility of data. If data is compatible, the results are compatible as well, and therefore follow a compatibility standard. So, one of the objectives of standardization is getting compatibility in studies all over the world to ensure that when someone analyzing an airport, for instance, and providing delay figures, the meaning is exactly the same as that of a different analyst in a different part of the world, analyzing the exact same issue for a different airport. It is clear that standardization cannot be established locally or unilaterally, but, rather, requires cooperation between many organizations.

ATM analysts would benefit greatly from having a given standard set of data. For instance:

- **Input data**: A standard set of input data parameters for specific types of studies with various accuracy levels for both the study and the data set. For example, the analysts would be certain that when choosing an "average day," it would be similar to one used by any other analyst, whatever the tool they use. Results would then be based on the same input parameters.
- **Output data**: It would be a great advantage if the ATM research and development community could have a standardized, but flexible, set of ATM metrics to determine safety, economics, capacity, or any other indication of ATM performance. Analysts could refer to a given metric that belongs to a standard, which would be valid, understood by all, and could be shared with other analysts. Note: Action Plan 2 and AP5 have started work to develop an ATM Performance Framework based on an International Organization for Standards (ISO) standard for Quality of Service and the International Civil Aviation Organization (ICAO) Required ATM System Performance (RASP)/Required Total System Performance (RTSP) approach.

It can be stated that a standardized set of inputs and output metrics would enable comparison of scenarios from any originating source. However, a question to ask is: Is a standard set of input and output metrics enough to ensure that scenarios and results are fully compatible and standard all over the world?

Standardization not only applies to input data and output metrics, but also to scenario development. For instance, if a given study requires conflict resolution; conflict detection and resolution rules are needed as inputs and conflict counts would be a result. However, when modeling the scenario, several conflict conditions should be used in order to enable conflict resolution to work properly. Therefore, scenario definition must be part of standardization.

Standardization in ATM modeling and analysis would be a great benefit; however it would require cooperation between organizations with regard to standard types of studies and standard accuracy requirements. Standard studies would require a standard set of input data, standard sets of output metrics, and standard scenario modeling requirements or settings.

5.3.2.2 Knowledge Sharing

A step towards standardization is knowledge sharing. As indicated above, standardization cannot be achieved locally; instead, it is a common and global goal to reach an understanding and agreement of standards. Knowledge sharing is an integral part to achieving those goals.

Knowledge sharing provides a way to reuse data, and share methodologies and models. In the ATM research community, it is very common that several analysts from different organizations will face the same problem, use similar methodologies and tools to solve the problem, and reach the same conclusions. Reusability implementation means that when a problem has been solved once, if the results and methodologies are shared, there is no need to address the problem in the future. There is a common understanding within the ATM analysis community that sharing information (data, methods, and results) is important; however, the formal sharing of information has been slow to implement. User groups have started to share information and the Validation Data Repository (VDR) can be used as a platform for Knowledge Sharing.

5.3.2.3 Certification/Validation

A step further in the standardization process is to achieve certification and validation of methodologies and tools. For instance, when a new model or update to an existing model is released, the analyst must question if the new model or update will be compatible with the current analysis.

Certification is needed to incorporate new models using a commonly agreed upon procedure and to support the use of different models to achieve common and validated results, even when the models have differences. For example, if two models produce different outcomes with similar inputs, it does not indicate a problem with the models, but a need to develop a validated approach pertaining to the use of the models.

Does a model need to be certified to provide accurate, reliable, or believable results and will certification of a model lead to more confidence in the results? These questions, although not within the scope of this discussion, needs to be asked.

One method for model and methodology certification is to identify and produce validated case studies. Such case studies could be used by analysts as test cases for current models, new models, and new releases.

6 Summary

The TIM entitled "Presentation and capability assessment of various fast-time simulation models" brought together 32 practitioners from the United States and Europe to provide developers with a forum to present their current and future modeling capabilities, identify and capture existing fast-time modeling capabilities, identify current and future modeling techniques, identify gaps in current fast-time modeling capabilities, and to identify sponsoring organizations needs and requirements.

As a precursor to the TIM, a modeling capability survey was sent to various developers and users to identify the current capabilities and gaps in the current modeling environment. The results of the survey have been provided and highlight the current capabilities and gaps in current models.

The results of the survey show that the functionalities presented in the surveys are well represented as indicated by the responses. However, the results indicate that gaps or areas with only a few responses need further consideration. These areas include; aircraft routing around moving weather cells, environmental concerns (emissions/noise/icing), enablers (communication/navigation/surveillance/information flow), human modeling, dynamic aspects, and flow management (AOC/ATM). Also, there were certain areas that many of the responses indicated would be difficult to add to the surveyed tool. These include; environmental concerns (noise/icing), airport surface navigation, enablers (communication/navigation/surveillance/information flow), human modeling, system errors, and flow management (AOC/ATM).

One can infer by the responses to the survey that many of the functionalities are contained throughout the various tools. This suggests a need for collaboration between the tools, either through a direct link or information exchange, including shared algorithms.

The format of the TIM consisted of two days of presentations by the developers and users followed by discussion. The third day provided the practitioners with the opportunity for open discussion on the future capabilities of the models, user needs, sponsor needs, as well as, analysis concerns. The TIM provided an excellent means to communicate with developers and users in identifying the needs and requirements for future modeling development efforts. The TIM provided incite into some of the needs of the developers and users not captured in the surveys, as well as analysis concerns such as validation, data integrity, standards, and knowledge sharing.

7 Abbreviations

AENA	Aeropuertos Españoles y Navegación Aérea
AOC	Airline Operations Center
AP5	Action Plan 5
AP9	Action Plan 9
ATC	Air Traffic Control
ATM	Air Traffic Management
CENA	Centre d'Études de la Navigation Aérienne
DFS	Deutsche Flugsicherung GmbH
DST	Decision Support Tool
EIT	Engineering & Information Technologies (EIT)
FAA	Federal Aviation Administration
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
IMC	Instrument Meteorological Conditions
INECO	Ingenieria y Economia del Transporte
ISO	International Organization for Standards (ISO)
MIDAS	Man-Machine Integrated Design and Analysis System
MIT	Massachusetts Institute of Technology
BADA	Base of Aircraft Data
NASA	National Aeronautics and Space Administration
NATS	National Air Traffic Services
NLR	Nationaal Lucht en Ruimtevaartlaboratorium
R&D	Research & Development
RASP	Required ATM System Performance
RTSP	Required Total System Performance
SICTA	Sistemi Innovativi per il Controllo del Traffico Aereo
SUA	Special Use Airspace
NAVAID	Navigational Aid
TFM	Traffic Flow Management
TIM	Technical Interchange Meeting
VDR	Validation Data Repository
VMC	Visual Meteorological Conditions

8 Reference Documents

[1] FAA/Eurocontrol Cooperative R&D: Action Plan 5, Operational Concept Validation Strategy Document, December 2003

[2] Odoni A., Bowman J., Delahaye D., Deyst J., Feron E., Hansman J., Khan K., Kuchar J., Pujet N., Simpson R., Existing and Required Modeling Capabilities for Evaluating ATM Systems and Concepts, Massachusetts Institute of Technology, March 1997

APPENDIX A – Capability Survey

Capability Survey – Page 1

Tool Name: ☐				
Definition: A tool is defined as an analytical model and/or simulation model				
Directions: Pages 1-4 - Please check the box of any criteria that applies to the tool with which you work, under the proper heading. Under "Current Capability", please indicate either a partial or full implementation. Page 5 - Provides an open-ended answer section with room to write additional functionality not described in the survey.	Current Capability Partial | Full or Classification	Enhancement planned/easily added	Not planning this enhancement/ Difficult to add	Pre/Post Processing Handles Missing Capability
Tool Description				
My tool can be classified as (choose one)				
Macroscopic - Low Detail (policy analysis, cost-benefit studies)[1]	☐	☐	☐	
Mesoscopic - Medium Detail (traffic flow analysis, cost-benefit analysis)[1]	☐	☐	☐	
Microscopic - High Detail (detailed analysis and preliminary design)[1]	☐	☐	☐	
My tool is				
Stochastic	☐	☐	☐	
Deterministic	☐	☐	☐	
other (write in): ☐				
Tool Functionalities				
Aircraft Performance				
My tool uses realistic aircraft performance features including:				
acceleration and deceleration	☐ | ☐	☐	☐	☐
range of aircraft	☐ | ☐	☐	☐	☐
aircraft speeds for all phases of flight*	☐ | ☐	☐	☐	☐
other (write in): ☐				
Trajectory Modeling - My Tool …				
Uses look up table(s) for AC performance	☐ | ☐	☐	☐	☐
Calculates AC performance	☐ | ☐	☐	☐	☐
Uses wind data in trajectory calculation	☐ | ☐	☐	☐	☐
Calculates optimal aircraft routing based on:				
wind	☐ | ☐	☐	☐	☐
great circle	☐ | ☐	☐	☐	☐
other (write in): ☐	☐ | ☐	☐	☐	☐
Calculates aircraft re-routing around:				
special use airspace	☐ | ☐	☐	☐	☐
moving weather cells	☐ | ☐	☐	☐	☐
conflicts	☐ | ☐	☐	☐	☐
Models aircraft routes				
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	☐ | ☐	☐	☐	☐
Environment - My Tool …				
Models airspace for special use	☐ | ☐	☐	☐	☐
Models moving weather cells	☐ | ☐	☐	☐	☐
Calculates aircraft emissions	☐ | ☐	☐	☐	☐
Calculates fuel burn	☐ | ☐	☐	☐	☐
Calculates noise levels surrounding airports	☐ | ☐	☐	☐	☐
Models atmospheric conditions	☐ | ☐	☐	☐	☐
icing	☐ | ☐	☐	☐	☐
wind	☐ | ☐	☐	☐	☐

Capability Survey – Page 2

Tool Name: ☐				
Definition: A tool is defined as an analytical model and/or simulation model				
Directions: Pages 1-4 - Please check the box of any criteria that applies to the tool with which you work, under the proper heading. Under "Current Capability", please indicate either a partial or full implementation. Page 5 - Provides an open-ended answer section with room to write additional functionality not described in the survey.	Current Capability Partial | Full	Enhancement planned/easily added	Not planning this enhancement/ Difficult to add	Pre/Post Processing Handles Missing Capability
Domain - My Tool Models …				
The en route environment	☐ | ☐	☐	☐	☐
as a series of sectors including handoff	☐ | ☐	☐	☐	☐
as a series of nodes in a network	☐ | ☐	☐	☐	☐
Models the terminal (approach and takeoff) environment	☐ | ☐	☐	☐	☐
as a series of sectors including holding area	☐ | ☐	☐	☐	☐
as a series of nodes in a network	☐ | ☐	☐	☐	☐
Models airports	☐ | ☐	☐	☐	☐
including runway usage	☐ | ☐	☐	☐	☐
exit probabilities	☐ | ☐	☐	☐	☐
intersection takeoffs	☐ | ☐	☐	☐	☐
runway occupancy times (landing rolls/takeoff rolls)	☐ | ☐	☐	☐	☐
runway dependencies	☐ | ☐	☐	☐	☐
including taxiway usage	☐ | ☐	☐	☐	☐
as assigned taxipaths	☐ | ☐	☐	☐	☐
as optimized taxipaths	☐ | ☐	☐	☐	☐
with aircraft size constraints	☐ | ☐	☐	☐	☐
with aircraft blocking	☐ | ☐	☐	☐	☐
with surface navigation (lighting, signs)	☐ | ☐	☐	☐	☐
including staging areas	☐ | ☐	☐	☐	☐
including gate usage	☐ | ☐	☐	☐	☐
as sources and sinks	☐ | ☐	☐	☐	☐
as individual gates	☐ | ☐	☐	☐	☐
including de-icing areas	☐ | ☐	☐	☐	☐
including ramp and ground control	☐ | ☐	☐	☐	☐
including departure queuing (sequencing and capacity)	☐ | ☐	☐	☐	☐
with departure sequencing and departure pad capacity	☐ | ☐	☐	☐	☐
with departure slot times	☐ | ☐	☐	☐	☐
Enablers - My Tool Models …				
Communication usage (e.g., bandwidth)	☐ | ☐	☐	☐	☐
human workload	☐ | ☐	☐	☐	☐
system workload	☐ | ☐	☐	☐	☐
aircraft avionics	☐ | ☐	☐	☐	☐
Surveillance coverage	☐ | ☐	☐	☐	☐
outages	☐ | ☐	☐	☐	☐
update rate	☐ | ☐	☐	☐	☐
Navigation equipage	☐ | ☐	☐	☐	☐
landing capabilities	☐ | ☐	☐	☐	☐
NAVAIDs	☐ | ☐	☐	☐	☐
GPS	☐ | ☐	☐	☐	☐
aircraft flight management systems	☐ | ☐	☐	☐	☐
aircraft avionics	☐ | ☐	☐	☐	☐
Information flow	☐ | ☐	☐	☐	☐
flight progress strips	☐ | ☐	☐	☐	☐
other (write in): ☐				

Capability Survey – Page 3

Tool Name: ☐				
Definition: A tool is defined as an analytical model and/or simulation model				
Directions: Pages 1-4 - Please check the box of any criteria that applies to the tool with which you work, under the proper heading. Under "Current Capability", please indicate either a partial or full implementation. Page 5 - Provides an open-ended answer section with room to write additional functionality not described in the survey.	Current Capability Partial | Full	Enhancement planned/easily added	Not planning this enhancement/ Difficult to add	Pre/Post Processing Handles Missing Capability
System Performance - My Tool Calculates …				
Aircraft throughput	☐ | ☐	☐	☐	☐
for airport arrivals and departures (by airport and runway)	☐ | ☐	☐	☐	☐
for TRACON/TERMINAL fixes (by fix)	☐ | ☐	☐	☐	☐
for en-route sectors (by sector)	☐ | ☐	☐	☐	☐
Aircraft flight/travel time	☐ | ☐	☐	☐	☐
for airport arrivals and departures (by airport and runway)	☐ | ☐	☐	☐	☐
for TRACON/TERMINAL fixes (by fix)	☐ | ☐	☐	☐	☐
for en-route sectors (by sector)	☐ | ☐	☐	☐	☐
Aircraft delay	☐ | ☐	☐	☐	☐
for airport arrivals and departures (by airport and runway)	☐ | ☐	☐	☐	☐
for TRACON/TERMINAL fixes (by fix)	☐ | ☐	☐	☐	☐
for en-route sectors (by sector)	☐ | ☐	☐	☐	☐
Instantaneous aircraft counts	☐ | ☐	☐	☐	☐
for sectors and centers	☐ | ☐	☐	☐	☐
for TRACON/TERMINAL areas	☐ | ☐	☐	☐	☐
for airports	☐ | ☐	☐	☐	☐
Number of aircraft cancellations	☐ | ☐	☐	☐	☐
Gate utilization	☐ | ☐	☐	☐	☐
Number of operations	☐ | ☐	☐	☐	☐
Number of aircraft holds	☐ | ☐	☐	☐	☐
Planned vs. actual times (totals and average)	☐ | ☐	☐	☐	☐
Planned vs. actual miles (totals and average)	☐ | ☐	☐	☐	☐
Miles in trail at runway and fix	☐ | ☐	☐	☐	☐
Number of aircraft delayed per phase of flight	☐ | ☐	☐	☐	☐
Number of aircraft during peak traffic periods in all phases of flight*	☐ | ☐	☐	☐	☐
Number of aircraft handled per sector	☐ | ☐	☐	☐	☐
Number aircraft held in penalty box	☐ | ☐	☐	☐	☐
Number of runway assignment changes	☐ | ☐	☐	☐	☐
Differences between actual push-back time and scheduled push back time	☐ | ☐	☐	☐	☐
Number of gate reassignments	☐ | ☐	☐	☐	☐
Number of deviations from flight plan	☐ | ☐	☐	☐	☐
Number of clearances per aircraft	☐ | ☐	☐	☐	☐
Number of clearances modifications per aircraft	☐ | ☐	☐	☐	☐
Number and type of conflicts detected in all phases of flight by altitude, controller, sector, center	☐ | ☐	☐	☐	☐
Number of runway incursions	☐ | ☐	☐	☐	☐
Number and type of conflicts resolved and how by altitude, controller, sector, center	☐ | ☐	☐	☐	☐
Number of operational errors both system and actors	☐ | ☐	☐	☐	☐
Number of point outs	☐ | ☐	☐	☐	☐
Number of handoffs	☐ | ☐	☐	☐	☐
Human - My Tool Models …				
Controller teams (planning & executive)	☐ | ☐	☐	☐	☐
Traffic Management (or multi sector) controller activities	☐ | ☐	☐	☐	☐
Pilot activities (workload)	☐ | ☐	☐	☐	☐
Airline dispatcher activities	☐ | ☐	☐	☐	☐
Human error	☐ | ☐	☐	☐	☐

Capability Survey – Page 4

Tool Name: ☐				
Definition: A tool is defined as an analytical model and/or simulation model				
Directions: Pages 1-4 - Please check the box of any criteria that applies to the tool with which you work, under the proper heading. Under "Current Capability", please indicate either a partial or full implementation. Page 5 - Provides an open-ended answer section with room to write additional functionality not described in the survey.	Current Capability Partial | Full	Enhancement planned/easily added	Not planning this enhancement/ Difficult to add	Pre/Post Processing Handles Missing Capability
Modeling - My Tool …				
Provides a detailed log of the simulation	☐ | ☐	☐	☐	☐
Provides output reports	☐ | ☐	☐	☐	☐
Provides custom output reports	☐ | ☐	☐	☐	☐
Allows for user interaction during the simulation	☐ | ☐	☐	☐	☐
Can model new aircraft	☐ | ☐	☐	☐	☐
Provides a user interface including:				
input pre-processor	☐ | ☐	☐	☐	☐
output post-processor animation	☐ | ☐	☐	☐	☐
output post-processor reporting	☐ | ☐	☐	☐	☐
Allows for probability distributions	☐ | ☐	☐	☐	☐
Includes optimization routines (please list)	☐ | ☐	☐	☐	☐
Handles dynamic aspects (other than routing) including				
resectorization	☐ | ☐	☐	☐	☐
restratification	☐ | ☐	☐	☐	☐
airport configuration changes	☐ | ☐	☐	☐	☐
system failures	☐ | ☐	☐	☐	☐
system errors	☐ | ☐	☐	☐	☐
Is written in				
object oriented code (ex. C++, Java, etc.)	☐ | ☐	☐	☐	☐
structure programming (ex. C, Fortran, etc.)	☐ | ☐	☐	☐	☐
other (ex. Simscript)	☐ | ☐	☐	☐	☐
Can accept external calls	☐ | ☐	☐	☐	☐
Traffic Flow Management - My Tool Models …				
Airline Operations Centers (AOC)	☐ | ☐	☐	☐	☐
airline priorities	☐ | ☐	☐	☐	☐
cancellation of flights	☐ | ☐	☐	☐	☐
banking operations	☐ | ☐	☐	☐	☐
boarding/unloading procedures (times)	☐ | ☐	☐	☐	☐
gate service times	☐ | ☐	☐	☐	☐
aircraft fueling	☐ | ☐	☐	☐	☐
flight information	☐ | ☐	☐	☐	☐
schedule information (Traffic Samples)	☐ | ☐	☐	☐	☐
gate scheduling	☐ | ☐	☐	☐	☐
Air Traffic Management Functions	☐ | ☐	☐	☐	☐
flight plan submission and evaluation	☐ | ☐	☐	☐	☐
flow control and delay advisory	☐ | ☐	☐	☐	☐
flight day management	☐ | ☐	☐	☐	☐
strategic weather information	☐ | ☐	☐	☐	☐
Separation Assurance - My Tool Provides …				
For Aircraft to Aircraft separation assurance	☐ | ☐	☐	☐	☐
For Aircraft to Terrain/Obstacle separation assurance	☐ | ☐	☐	☐	☐
For Aircraft to Airspace separation assurance	☐ | ☐	☐	☐	☐
Conflict Detection and Resolution - My Tool Performs …				
Conflict detection	☐ | ☐	☐	☐	☐
Conflict resolution:	☐ | ☐	☐	☐	☐
based on mathematical equations (algorithmic)	☐ | ☐	☐	☐	☐
based on a resolution rulebase	☐ | ☐	☐	☐	☐
based on human interaction	☐ | ☐	☐	☐	☐
based on delay (resolves conflict by delaying aircraft)	☐ | ☐	☐	☐	☐
Aircraft conflict resolution on:				

Capability Survey – Page 5

Tool Name: ☐

Directions: Please provide written comments to the following:

1. List an functionality not included in page 1 of the survey or identify any functional needs or potential technical solutions that may be relevant.

2. What is the typical use of the tool in your organization or by your customers organization? If possible, include kinds of experiments, questions answered)

3. Does your tool have the ability to integrate with other tools? If so, list those tools and how they integrate (input/output data, HLA, DIS, other distributed simulation method, etc.)

APPENDIX B – Model Description and Reference

This appendix provides a brief description of the surveyed models.

AwSim

AwSim is a general-purpose trajectory and target simulator aimed at providing a realistic air traffic data source for ATC/ATM system. The main output produced by AwSim is a stream of trajectories (i.e. objects encapsulating a 4-dimensional profile of a moving vehicle in an earth center coordinate system). The segments from which trajectories are built can be made to snap to an airspace structure (i.e. aerodomes, fixes, and airways) or alternatively, they can be generated in a free-flight unrestricted fashion. The user can set the parameters that control the statistical distribution functions from which the population of segments is drawn. The variables under control (all of which have their separate distribution function) are: segment speed, segment length, Gaussian transverse deviation, segment altitude, start and end location of the trajectory, number of segments in a trajectory and start time. AwSim was developed by Aerospace Engineering and Research Associates, Inc.

Future ATM Concepts Evaluation Tool (FACET)

FACET is a tool used to conduct research and exploring advanced ATM concepts in the En Route and TFM environments. It can be used for both real-time applications and off-line-analysis. FACET has been used for conflict detection and resolution, DST benefits studies, Dynamic Density studies, and regional metering studies. FACET has a visualization feature which can be used for off-line analysis and real-time planning applications. FACET was developed by the NASA Ames Research Center.

HERMES

HERMES is a fast-time simulation to evaluate runway capacity and operations timing under current and future demand and technological improvements. It can also be used to evaluate changes in infrastructure such as runway length modifications. While full airport operations including taxiing are simulated, HERMES puts greatest emphasis on runway operations. HERMES takes experimental recording of aircraft flight paths as input and the principal output is averaged delays. HERMES is effective in providing aggregate results and has been designed to account for the specific rules used at Heathrow for computing very accurate capacity estimates. HERMES is reportedly able to achieve an accuracy of 3/4 movements/24hr, as compared to 12-24 movements/24hr for SIMMOD or TAAM. HERMES also provides detailed simulation of most events occurring during take-off and landing phases. Hermes was developed by the British Civil Aviation Authority/National Air Traffic Services (CAA/NATS).

National Airspace Resource Investment Model (NARIM)

NARIM provides a modelling and analysis capability to examine airspace concepts associated with future advances to the National Airspace System (NAS) and to provide a NAS perspective to the research and investment allocation process.

The NARIM system consists of three interrelated parts:

- Operational modelling analyses the movement of aircraft through the NAS to determine the impacts that new concepts will have on the overall NAS performance.
- Architectural/Technical modelling provides a means of assessing how procedural/system changes affect the hardware/software components of the NAS infrastructure.
- Investment analysis modelling provides the user with a methodology to cost effectively trade between alternatives for a system, trade requirements within a system and across system and procedural investment alternatives, trade between services to be provided/included into the NAS, balance risk, and assess the investment decision as a of part of a total research portfolio.

The following NARIM tools are in use:

- Find Crossing - Mapping of trajectories to sectors and airspace restrictions.
- Total Traffic Tool - An extension of Find Crossings, it is used to analyse potential conflicts and characteristics of conflicts.
- ETMS Parser - A tool used to parse ETMS data.
- Optimised Trajectory Generator (OPGEN) - OPGEN produces 4-D flight trajectories for user specific Flight Management System (FMS) cost indices based on winds aloft and active Special Use Airspace (SUA).

The National Airspace System Performance Analysis Capability (NASPAC)

The National Airspace System Performance Analysis Capability (NASPAC) Model is a discrete event-simulation model that measures system performance. NASPAC tracks aircraft competing for air traffic control resources as they progress through the NAS. It enables the FAA and the aviation industry to study the effects of proposed changes in design, structure and configuration of the various airspace and airport components of the NAS. NASPAC evaluates system performance for 80 of the nation's busiest airports. The NASPAC airport and airspace system is described principally in terms of:

- airport capacities (IMC and VMC)
- arrival and departure fixes
- aircraft routes
- ATC sector geometries and capacities
- en route miles-in trail restrictions
- demand (scheduled and unscheduled)

NASPAC provides a system-level performance measurement (primarily due to changes in demand and capacity). It applies a weather annualization methodology to reflect system impacts of representative weather scenarios.

National Flow Model

The National Flow Model (NFM) serves as a test bed for evaluation and development of new ATM operational concepts, system architectures and benefits assessments. The NFM simulation enables quantifiable analysis of NAS-wide flow interactions at the network level; it is developed to represent current and future traffic flow strategies. The NFM areas of investigation include; system performance (NAS-wide delay reduction/throughput benefits, NAS-wide impact of capacity increases, NAS system predictability, Inputs to technology investment and economic benefits analysis), Operations (Coordinated flow management and execution, Convective weather avoidance routing, Airspace utilization), and ATC Infrastructure (Traffic Flow Management control strategies, NAS-wide message/link capacities for communication technologies). NFM was developed by Boeing.

OPAS

OPAS is a family of simulators en-route, approach traffic, and a combination of en-route and approach for R&D and performance studies. OPAS is easy to maintain, flexible, modular (ability to interchange components), adapts to different concepts, and is used to test different conflict solving algorithms. OPAS:

- Tests new concepts and new algorithms
- Uses different navigation logics, dynamic choice of trajectory
- Provide figures to evaluate performance indicators
- If needed compute these performance indicators during simulation

OPAS-TMA is designed for the terminal environment. The main goal of OPAS-TMA is to produce realistic aircraft trajectories in the vectoring area. The scenario evaluations are then based on the use of holding stacks, time and length of trajectories in the TMA, ground delays, etc. The trajectories generated with OPAS-TMA can be used as an input for noise models when doing environmental studies.

OPAS and OPAS-TMA are developed by CENA

OPGEN

The Optimised Trajectory Generator (OPGEN) produces 4-D flight trajectories for user specific Flight Management System (FMS) cost indices based on winds aloft and active Special Use Airspace (SUA). The trajectories generated by OPGEN are used as inputs to other analysis tools or simulation models.

RAMS

The Reorganised ATC Mathematical Simulator (RAMS) is a fast-time discrete-event simulation software package providing functionality for the study and analysis of airspace structures, Air Traffic Control systems and future ATC concepts. The objective of RAMS is to model a wide range of ATC concepts, producing analytical results in a short period of time, allowing more time for comparative analysis while reducing the time for data preparation. The results of this simulation modelling offer insights to Air Traffic Management (ATM) planning and organizational proposals, from high level macro-views to in-depth micro-view scenarios. RAMS features include an integrated editor and display tool, rapid data development, stochastic traffic generation, 4D flight profile calculation, 4D sectorisation, 4D spatial conflict detection, AI rule base conflict resolution, 4D resolution manoevering, workload assignment, TMA runway/holdstacks, airspace routing, free-flight and RVSM zones, graphics animation, and a reporting package. RAMS development and maintenance is performed by ISA-Software.

Regional Traffic Model

The Regional Traffic Model (RTM) is a regional model that simulates multi-sector airspace. It is a mixed continuous time/discrete event model that includes; dynamic aircraft models, human task models for controllers & pilots, and models of airports, airspace, and ATC/ATM/CNS infrastructure elements. The RTM was developed by Boeing.

SDAT

The Sector Design Analysis Tool (SDAT) is a computer program designed to assist Air Route Traffic Control Center (ARTCC) Airspace and Procedures Specialists, and airspace analysts in the design of airspace. SDAT is intended to provide the airspace designer with a fast, easy, and accurate way to develop and evaluate proposed changes to airspace structure and/or traffic loading. SDAT is easy to use and is compatible with many different types of airspace and traffic data. SDAT allows one to view airspace structures and features in two and three dimensional (2-D and 3-D) representations and to rotate the entire display so that it can be viewed from various angles. One can view specific airspace features including airways, adapted routes, NAVAIDs, fixes, airports, etc. (i.e., HOST Adaptation data). One can also view flight plans and flight track data from a host of different sources including HOST System Analysis Recording (SAR) recorded air traffic information, Enhanced Traffic Management System (ETMS), and Automated Radar Terminal System (ARTS). In addition, one can modify, add or delete Adaptation and air traffic data.

SDAT is able to perform various analyses, such as conflict potential, and fix and airspace loading, using either the original or modified Adaptation data and/or traffic information. Predictions of conflict potential, traffic and airspace loading, and impacts on the airspace user can be generated for any proposed combination of airspace and traffic data.

SDAT produces reports describing Adaptation and traffic modifications, and other information of interest to the user. The Adaptation Modification Report is produced in a format that is compatible with the HOST Adaptation Controlled Environment System (ACES), thus reducing the work required to re-code and enter the data.

SDAT also produces reports and graphs summarizing the results of your analyses in a readily usable format. Reports and graphs generated include traffic, fix, sector, and sketch loading, adaptation and traffic modifications, conflicts, and impacts of changes, and flights affected.

SIMMOD

Airport and Airspace Delay Simulation Model (SIMMOD) is an event-step simulation model which traces the movement of individual aircraft and simulated ATC actions required to ensure aircraft operate within procedural rules. SIMMOD computes the impact on aircraft delay and fuel consumption and uses a wide variety of parameters. SIMMOD inputs include traffic demand and fleet mix, route structures (both in the airspace and on the airport surface), runway use configurations, separation rules and control procedures, aircraft performance characteristics, airspace sectorization, interactions among multiple airports, and weather conditions. SIMMOD uses a node-link structure to represent the gate/taxiway and runway/airspace route system. Input parameters depending on aircraft type include: permissible airborne speed ranges for use by ATC, runway occupancy times, safety separations, landing roll and declaration characteristics, taxi speeds, and runway/taxiway utilization. Gate utilization depends on aircraft type and airline. Users control the timing of the simulation and the desired output reports. A start time and a termination time may be specified for the simulation, as well as a time for periodic reports to be generated. Users provide data regarding the occurrence of various simulation events. These events include aircraft arrival/departure, airport configuration plan changes, and changes in weather conditions. SIMMOD output consists of reports which provide statistics describing aircraft delay, travel time, and fuel consumption. A user may also request a simulation log containing data on various simulated events. SIMMOD also has a post-processing animation system which shows the movement of aircraft on the airfield and in the airspace.

SIMMOD PRO

Simmod PRO! is an ATAC-proprietary derivative of the widely used Airport and Airspace Simulation Model, SIMMOD™. In addition to enhanced graphical user interface, input preparation, and animation capabilities, Simmod PRO! includes an advanced simulation engine that greatly expands the capabilities to simulate the dynamics, variability, site-specific features and situation-specific factors in air traffic operations. Simmod PRO! incorporates powerful, rule-based logic as input to the simulation, which enables airport and airspace simulation analysis that cannot be addressed by other models.

Simmod PRO!'s modeling power is derived from the rules that can be specified to query the state of the simulation and provide dynamic decision-making. An aircraft's air route or ground path, for example, can be changed, as simulated conditions require. This ability allows the modeling of:

- Runway switching/balancing
- Departure queue sequencing
- Aircraft turn-around and banking criteria
- Gate usage and gate-hold strategies
- Complex interactions among neighbouring multiple airports
- Dynamic airfield and airspace rerouting
- Probabilistic decisions
- Operational dependencies

- Look-ahead capabilities
- Ground vehicles (e.g., towing, fueling, catering, baggage)
- Disruptive events (e.g., weather, system failures, runway closures)
- Human resources and activities (e.g., controllers, pilots, airline)
- Advanced operating concepts

The rule-based input provides for specifying actions to be taken by the simulation based on the state of the system. Examples of the dynamic states of the system that can be queried to control the simulation include:

- Departure queue length
- Ground or airspace congestion
- Gate occupancy
- Current level of air or ground delay
- A flight's aircraft type and airline
- A flight's origin or destination

SIMMOD PLUS

Simmod PLUS! is an ATAC-developed product which includes the SIMMOD™ engine plus a robust set of tools to enable users to prepare required input, exercise the model, and analyze output results. Simmod PLUS! can significantly reduce SIMMOD™ application development time by providing a user with the following features:

- An easy-to-use graphical user interface to design, build, and execute the simulation
- A Network Builder that enables a user to graphically construct the node-link structure of the airport/airspace system being studied
- Relational database tables that store and manage simulation data
- Error and consistency checks of input data
- Easy operation with other desktop applications (Excel, Access, etc.)
- A 2D traffic animator that facilitates input preparation and aids in analysis and presentation of results
- A reporting module that allows detailed results to be quickly analyzed

The Network Builder provides the capability to model multiple airports, each having multiple runways, taxiways, gates, deicing areas, staging areas, departure queues and concourses, as well as extremely detailed airspace routes and sectors. Importing CAD drawings of the airfield and terminal into the simulation allows quick development of a very accurate and detailed ground model. A user can build a high-fidelity airspace model with the aid of the Simmod PLUS! Network Builder, which can display airspace boundaries, navigation aid and fix locations, and standard GIS data. In addition, the Network Builder incorporates many tools that allow the analyst to easily implement the complex capabilities of the simulation engine.

The Simmod PLUS! 2D Animator presents a detailed view of simulated aircraft operations, both on the ground and in the air. The user can view detailed flight and aircraft information during the animation replay simply by clicking on the aircraft's icon. The Animator can import and display graphical information as background to the animation, such as noise contours, terrain, and other GIS data.

The Reporting Module includes over 800 preset reports as well as the capability to create customized reports. It enables the analyst to easily determine output statistics down to the aircraft level or at any aggregate level. In addition, output is compatible with other desktop applications, allowing for ease of additional data analysis.

TAAM

TAAM (Total Airspace & Airport Modeller) is a large scale detailed fast-time simulation package for modeling entire air traffic systems, developed by The Preston Group (TPG) in cooperation with the Australian Civil Aviation Authority (CAA).
TAAM can be used as a planning tool or to conduct analysis and feasibility studies of ATM concepts. TAAM can simulate most ATM functions in detail and can provide scenario generation for real-time ATC simulators. The simulations cover the entire gate to gate ATM process, generally in more detail than competing models.

A TAAM simulation consists of a collection of user provided data relevant to the problem at hand and its modeling requirements. TAAM takes as input the air traffic schedule, environment description, aircraft flight plans, air traffic control and output control rules. It uses them in performing airport and airspace usage, conflict detection and resolution, and aggregate metrics calculations with its internal algorithms and user defined rulebases.

TAAM modules include an interactive graphical fast-time simulation tool which provides the user with a 2D or 3D view of the airpace or airport; a real-time air traffic monitoring tool with simulation capability; and a reporting tool which can be used to generate graphs and tables from data generated by the simulation. Simulations can be interrupted and restarted and key aspects of the model, such as conflict resolution and airport resource usage are controlled by rulebases which may be edited by the user during a simulation run. 'Live' graphical display of the simulation can be selected and customizable reporting is available. The simulation can also be run unattended in batch mode, with no graphics. During the simulation, statistics are gathered by the reporting program and written to a report file. This file is used by the Report Presentation Facility to construct the text and graphical reports desired by the user.

TARGETS

Terminal Area Route Generation, Evaluation and Traffic Simulation
CAASD has been working closely with the FAA and other parties to develop and assess various near-term terminal area procedures with the aim of improving airline service. One

result of CAASD’s work is TARGETS (or Terminal Area Route Generation, Evaluation, and Traffic Simulation), a research tool that, has been used to interactively design routes with controllers and pilots. TARGETS has also been used for route assessment, for design refinement from flight tests, and for controller familiarization with new procedures.

TARGETS aids RNAV route definition in several ways:

- By displaying the route on the video map used by controllers.
- By deriving latitude and longitude coordinates for the proposed waypoints based upon video map location.
- By performing preliminary flyability checks for user-supplied aircraft performance characteristics.

Using TARGET’s traffic simulation capability, controllers can familiarize themselves with the new procedure and examine mixed equipage issues and other operational issues such as taking an aircraft on the route, and sequencing and merging aircraft onto the RNAV. With CAASD assistance, controllers for several sites created traffic scenarios to familiarize themselves with such operational issues.

TARGETS consists of a route definition capability, as well as a terminal area traffic simulation.

By simply pointing and clicking the mouse to derive latitude and longitude coordinates (and simultaneously creating the desired flight path), TARGETS allows airspace planners and procedure developers to instantaneously define an RNAV Departure Procedure (DP), Standard Terminal Arrival Route (STAR), or an approach. Altitude and/or speed control application is simple and can be easily changed (or, in controller parlance, "amended").

The Evaluation or "flyability" check is a true time saver with respect to understanding the feasibility of the new RNAV procedure. TARGETS users can instantaneously analyze the procedure’s flyability (which is based on speed/altitude constraints and aircraft performance). The procedure developer can import topographical map data and/or specify restricted airspace areas to maximize airspace development while designing a procedure that is environmentally sensitive.

The terminal traffic simulation capability of TARGETS assists controllers in becoming familiar with the new RNAV procedure. The TARGETS workstation can be installed in any air traffic control facility for controller training and route familiarization activities.