RTO-55 Final Report

Human Performance Modeling of En Route Controllers

Prepared For:

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1 Introduction

Many of the Advanced Air Transportation Technologies (AATT) concepts being proposed to advance air traffic control (ATC) and air traffic management (ATM) involve human-centered automation and decision aiding concepts. In the distributed air/ground traffic management (DAG-TM) environment alone, there are several concepts within each concept element in which the system performance is highly dependent on the performance of the human operators. Just as it would be cost-prohibitive to use wind tunnel testing exclusively in the aircraft design process to determine concepts worthy of further investment, so it is for full human-in-the-loop experimentation for all AATT concepts. And, just as computational fluid dynamics has become an integral part the aircraft design process, so should human performance modeling and simulation be integral to ATC/ATM system design and development. Ideally, we would like to develop a synergy between model-based analysis and the human-in-the-loop experimentation that is conducted, as shown in Figure 1. The intention is that by focusing on experimentation, better model validation of the human/system models will occur. In addition, better human/system models will provide for a better focus on experimentation.

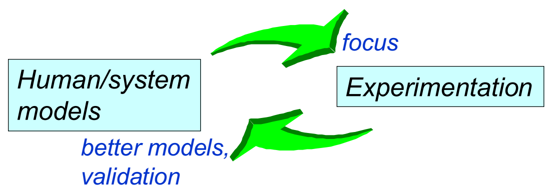


Figure 1. Synergy between models and experiments

The goal of RTO-55 is to develop a human performance model of en route controllers in today's operations. The model would serve as a baseline for comparison with new concepts to be evaluated at some time in the future. In addition, the model demonstrates the type of human performance data that could be collected and analyzed for today's operations.

2 Baseline Air Traffic Scenarios

The first task of this project was to define air traffic scenarios that will constitute the baseline for performance measurements. MA&D met with key AATT staff at Ames Research Center to understand the short-term (i.e., the period of performance of this contract) and long-term needs of the of the AATT project. Based on their needs, MA&D proposed a set of scenarios that reflect today's operations. This set of scenarios was confined to those that can be prudently modeled within the scope of this contract. MA&D has created scenarios using generic airspace/aircraft attributes. This generic airspace model has enabled us to focus on the primary objective of building a complex model of en route controller tasks, responsibilities, procedures, and decision-making processes in today's operations.

2.1 Airspace Description

The simulated airspace consists of controlled and uncontrolled airspace. Controlled airspace is defined as the airspace where the controllers actions are modeled. Uncontrolled airspace is defined as airspace that is needed to support the modeling, but the controller actions are not modeled. Specifically, uncontrolled airspace supports handoffs for aircraft headed to and from the simulated airspace. Uncontrolled airspace extends 30 nm from the controlled airspace perimeter.

The controlled airspace consists of four high altitude (FL190 – FL600 ft) and two arrival (8,000 ft – FL600 ft) sectors with geometries as depicted in Figure 2. The dimensions of each sector are as follows:

- High altitude sectors 1 & 2 are 100 nm wide east-west and 80 nm wide north-south
- High altitude sectors 3 & 6 are 200 nm wide east-west along the outside perimeter and 70 nm wide north-south
- High altitude sectors 4 & 5 are 100 nm wide east-west and 150 nm wide north-south along the outside perimeter

Terminal Radar Approach Control (TRACON) airspace extends from ground level to 8,000 feet. The TRACON airspace is not specifically modeled, but its circular boundary is depicted in Figure 2. The altitude of the metering fixes is where the TRACON and the low altitude sector boundary meet (i.e., 8,000 feet). The metering fixes, depicted in Figure 2 as solid circles, are located at a radial distance of 40 nautical miles from the center of the TRACON.

2.2 Aircraft/Track Description

Each aircraft track is assigned an aircraft type. The aircraft type is proportionally distributed as a given percentage amongst the other types of aircraft. There are six aircraft types modeled. Each aircraft type has a preferred cruise airspeed and a range of preferred altitudes as follows:

- Aircraft type 1
    - 10 % of the aircraft
    - cruise speed of 400 knots
    - altitude range from FL280 to FL350

- Aircraft type 2
    - 25 % of the aircraft
    - cruise speed of 420 knots
    - altitude range from FL280 to FL330

- Aircraft type 3
    - 15 % of the aircraft
    - cruise speed of 440 knots
    - altitude range from FL320 to FL340

- Aircraft type 4
    - 20 % of the aircraft
    - cruise speed of 460 knots
    - altitude range from FL320 to FL370

- Aircraft type 5
    - 25 % of the aircraft
    - cruise speed of 480 knots
    - altitude range from FL300 to FL370

- Aircraft type 6
    - 5 % of the aircraft
    - cruise speed of 480 knots
    - altitude range from FL320 to FL370

- A further requirement of the aircraft is that cardinal flight rules determine their altitude based upon their general heading of eastbound or westbound.

Aircraft are assigned an initial cruise altitude using a uniform distribution of the odd-

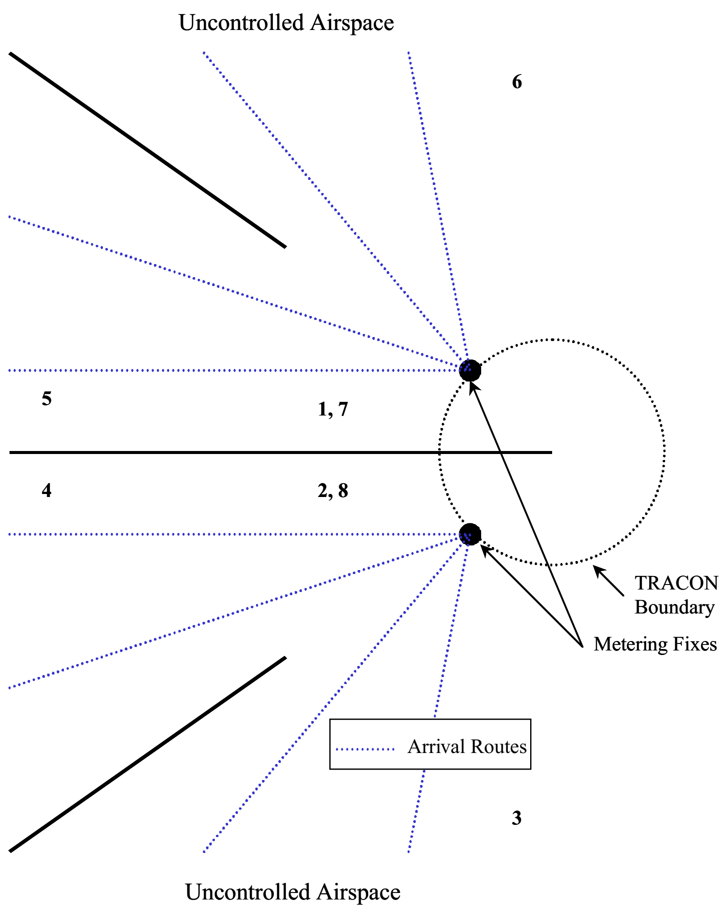


Figure 2. Airspace Boundaries and Arrival Routes

numbered or even-numbered altitudes within their assigned range. The speed and altitude assignments and the percentage allocation of aircraft types is a means to ensure that our model design is robust and can readily handle real world scenarios consisting of various traffic mixes should such data become available.

2.3 Scenario Description

The following are traffic pattern and miscellaneous specifications:

- 70% of the aircraft tracks are over-flights utilizing the National Route Program
    - Their initial locations are randomly distributed along the outside perimeter of the uncontrolled airspace.
    - Their initial headings are chosen so that the tracks cross through at least two sectors of controlled airspace before departing the simulated airspace (e.g., an aircraft track initiated on the south boundary of Sector 3 should have a heading that is north, northeast, or northwest.) There is randomness in the initial heading while still maintaining the "flying through two sector of airspace" requirement.

- 30% of the aircraft tracks are arrivals for a Level 5 airport located at the center of the TRACON.
    - Their initial locations are uniformly distributed among the eight arrival routes depicted in Figure 2.
    - Their initial headings are chosen so that the tracks fly a straight trajectory from the outside perimeter to the metering fix.
        - Tracks initiating in Sectors 5 or 6 fly to the Sector 1 metering fix.
        - Tracks initiating in Sectors 3 or 4 fly to the Sector 2 metering fix.

        The aircraft descend at a constant idle thrust descent rate from their cruise altitude to the final metering fix altitude of 8000 feet.

- An airline with hub-n-spoke operations has a "rush" over a 20 minute period that can significantly change the percentage of over-flights to arrivals of a typical traffic mix. One rush per hour of simulation was modeled. The percentage of over-flights to arrivals was modified to ensure that a total of at least 30 aircraft will cross the two metering fixes over a 20 minute period.

- The rate that new tracks are initialized (i.e., the rate at which new tracks enter the modeled airspace) corresponds to having a maximum sector loading of 20 aircraft for any one sector over a one hour simulated scenario. This rate is meant to emulate traffic management functionality.

- Wind is assumed to be constant and uniform at a speed of 60 knots blowing due east.

Departure flows are not being modeled at this time in our generic airspace. MA&D believes that the many of the workload issues pertaining to departures is currently accounted for in today's operations through sector design, flow conformance, and procedural restrictions. Including departures in our generic simulation without accounting for these other factors would artificially increase the simulated workload in our models. On the other hand, attempting to determine a sector design or flow conformance criteria that would work with our generic airspace is not within the scope of this project.

3 En Route Controller Model

The model architecture is designed for future expansion as the need for higher fidelity and/or more complex scenarios grows. Our goal is to have a modular design to provide the capability to exchange models of airspace, procedures, etc., with other models that become available.

3.1 Micro Saint Description

Micro Saint is a Windows discrete event simulation tool that could be used for a wide variety of modeling applications. For this project, Micro Saint provides the capability to model human performance in complex systems. The basic building block of defining human/system performance in Micro Saint is a task network model. In essence, a task network model is no different from a functional flow diagram. In fact, this is what makes task network modeling attractive – it extends a function and task analysis into a predictive model based around a network representation of human and system activity. This basic task network is built via a point-and-click drawing palette. Through this environment, the user creates a network, as shown in Figure 3, including specific task behavior and links with other system elements. Associated with each task are details describing task timing, error consequences, cognitive workload, resource and information requirements, and how the task interacts with other system tasks and events. Models can be as complex or as simple as the issues being addressed require. Networks of tasks can be also embedded within networks, allowing hierarchical construction. This facilitates iterative model development and refinement of models since more complex task behavior can easily be added to an existing model when higher-fidelity analysis is appropriate.

Micro Saint supplements basic task networking with the capability to perform optimization. For a given task network, input parameters representing design variables can be optimized for a desired solution. An example of optimization that might apply to AATT concepts would be to determine the optimal time horizon for conflict resolution that minimizes controller workload while maximizing aircraft maneuver efficiency. If the controller resolves a conflict based on a large time horizon, the probability of false alarms is higher, resulting in unnecessary controller actions and aircraft maneuvers. On the other hand, if the conflict detection time horizon is very short, the probability of false alarms or missed alerts is very small, but the resolution maneuvers are more inefficient, requiring more vectoring off of the intended flight path.

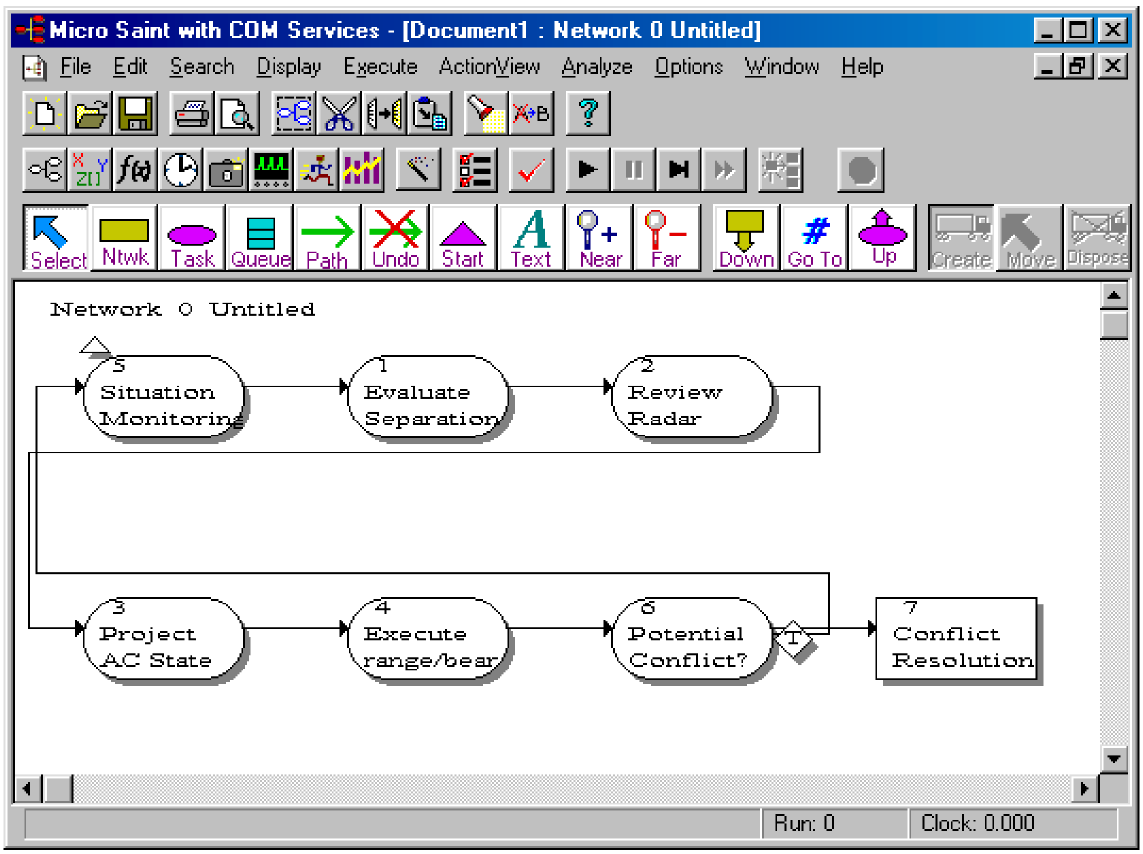


Figure 3. Task Network Representation

3.2 Modeling of En Route Controller Tasks

3.2.1 List of Modeled Tasks

The focus of the model development was on the tasks that the controller does continuously and nominally during a regular shift. Although controllers perform many different types of tasks, by limiting the model to a specific subset of tasks, MA&D had the opportunity to model those tasks in an accurate and complete way.

The tasks modeled for this project are:

R-side Tasks

- Situation Monitoring
    - Detect conflicts
    - Detect metering and spacing violations
    - Initiate transfer and acceptance handoffs
    - Monitor radio
- Conflict Resolution
- Metering Conformance
- Spacing Conformance
- Radio communication with pilot

D-side Tasks

- Manage flight strips
- Assist with pilot readback of clearances
- Coordinate with other sectors
    - Ground/ground communication

3.2.2 Initial Model Development

MA&D used a proven approach to accurately model en route controller tasks. The first step is to build a task network representation based on existing documentation that describes en route controller job functions, activities, tasks, roles, responsibilities, and procedures. MA&D has considerable experience in this area gained from a thorough literature review performed during RTO-34. The three documents used in this step are discussed below:

1. The FAA Air Traffic Control Handbook (Reference 1) lists the responsibilities of en route controllers. A limitation to the handbook is that it lacks a formal sequence of tasks corresponding to specific controller activities. Fortunately, the RTO-34 literature search revealed that two other documents did address the issue of task sequence through a formal job task taxonomy and information task processing, respectively.

2. FAA Civil Aeromedical Institute document (Reference 2) defines top-level controller job functions as activities. Sub-activities are the next level and describe work performance actions. The third level, tasks, describes units of work performance. Task elements are the final level of decomposition and describe the most fundamental steps and actions required to complete a task. This document contains 61 pages, 6 activities, 39 sub-activities, 400 tasks, and several hundred independent task elements. It does not differentiate between R-side and D-side positions, but instead represents the tasks that would be performed if a single controller were working a sector.

3. The CTA document (Reference 3) defines the information processing tasks

performed by en route controllers. Much of the information presented was in the form of a task network representation so it was easily implemented in the Micro Saint model.

After the model was developed to an adequate level of maturity, subject matter experts arranged through the National Aviation Research Institute (NARI) met with MA&D researchers to step through the task network representation. Four controllers from the Denver Center, in two groups of two, participated in this phase for one day each. The goal was to confirm that the sequence of tasks provides an adequate representation. MA&D also had the controllers suggest task times and relative levels of workload for each of the tasks to initially populate the model. The controllers were able to explain in much greater detail the tasks and procedures as described in the documentation. The initial model was enhanced greatly based on their input.

3.2.3 Multi-Tasking Capability

It is widely accepted that all controllers must multi-task to be efficient at their jobs. A key attribute to the accuracy of the model is the capability to enable multi-tasking in a realistic manner. Based on the comments from the Denver Center controllers, multi-tasking is modeled in the following way:

1. Situation Monitoring can be performed in parallel to all other tasks
2. Handoffs can be performed in parallel to all other tasks (including other handoffs) unless they are resource limited (see #5).
3. Conflict resolution and spacing/metering conformance can only be performed one at a time (in serial).
4. Higher priority conflicts (short-term) will interrupt lower priority tasks such as long-term conflicts and/or spacing and metering tasks.
5. Tasks that require radio, trackball, and/or keyboard resources can temporarily prevent multi-tasking (e.g., a controller can visually detect two handoffs simultaneously, but the ability to accept the handoff requires the use of the trackball so he/she can only accept the handoff one at a time).

3.2.2 Task Network for Automated Handoff

The model consists of one task network for each major task. The automated handoff task is depicted in Figure 4 as an example to illustrate a typical task network representation in Micro Saint. (Note: the entire model is available to examine and demonstrate since both Micro Saint and the model described in this document are deliverables for RTO-55.) TC is the transferring controller whereas RC is the receiving controller. The handoff task requires both independent and interdependent actions by both controllers. As an example, the transferring controller cannot give the aircraft the new sector's frequency until the receiving controller accepts the handoff. If the receiving controller is occupied with other tasks, the transferring controller would have to call the receiving controller to get permission to handoff the aircraft prior to the aircraft crossing the boundary.

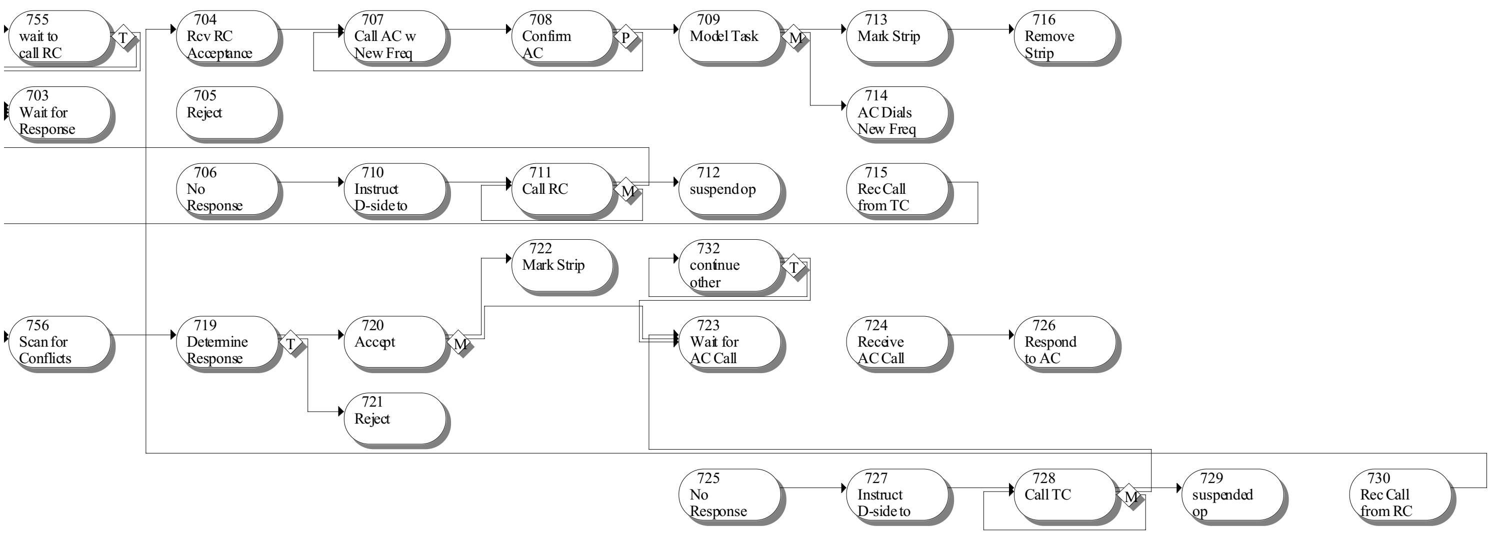


Figure 4. Task Network for the Automated Handoff

3.3 Controller Awareness Boundary

In today's operations, controllers are aware of traffic entering their sector from two techniques. The first technique occurs when an aircraft is approximately ten minutes from entering a sector. A flight strip for that aircraft is automatically printed out and the D-side controller places the flight strip in the strip bay. Since the R-side has visibility to the strip bay, occasional scans of the flight strips maintains their awareness of aircraft that will be entering his sector. The information about this aircraft is usually not accurate enough to perform conflict detection against other aircraft in the sector. Instead, R-side controllers rely on a second technique – they scan their radar displays outside their sector boundaries to see what traffic is entering their sector. Their displays are typically configured so that aircraft within a few minutes of the boundary are visible to the controller. This technique is modeled by assuming that all aircraft three minutes from a sector are included in that controller's awareness (see Figure 5). This time is slightly greater than the time that the automated handoff is initiated.

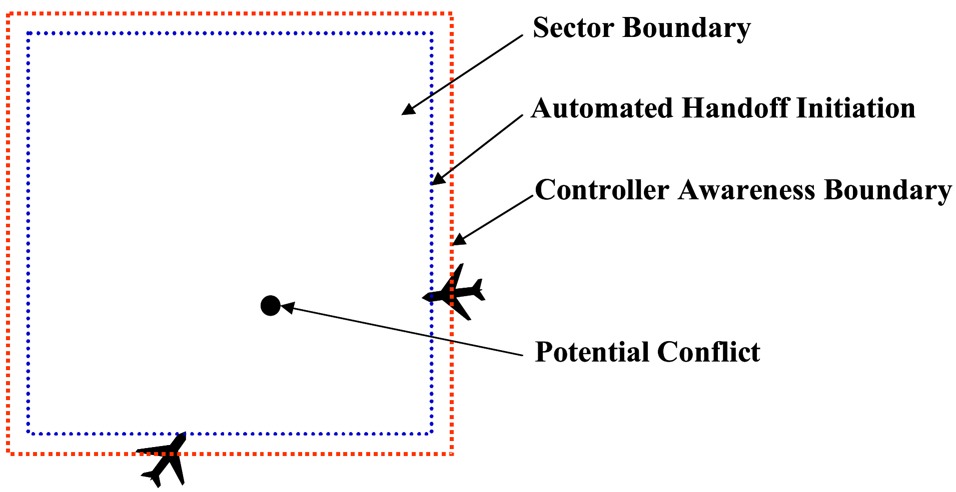


Figure 5. Controller Awareness Boundary

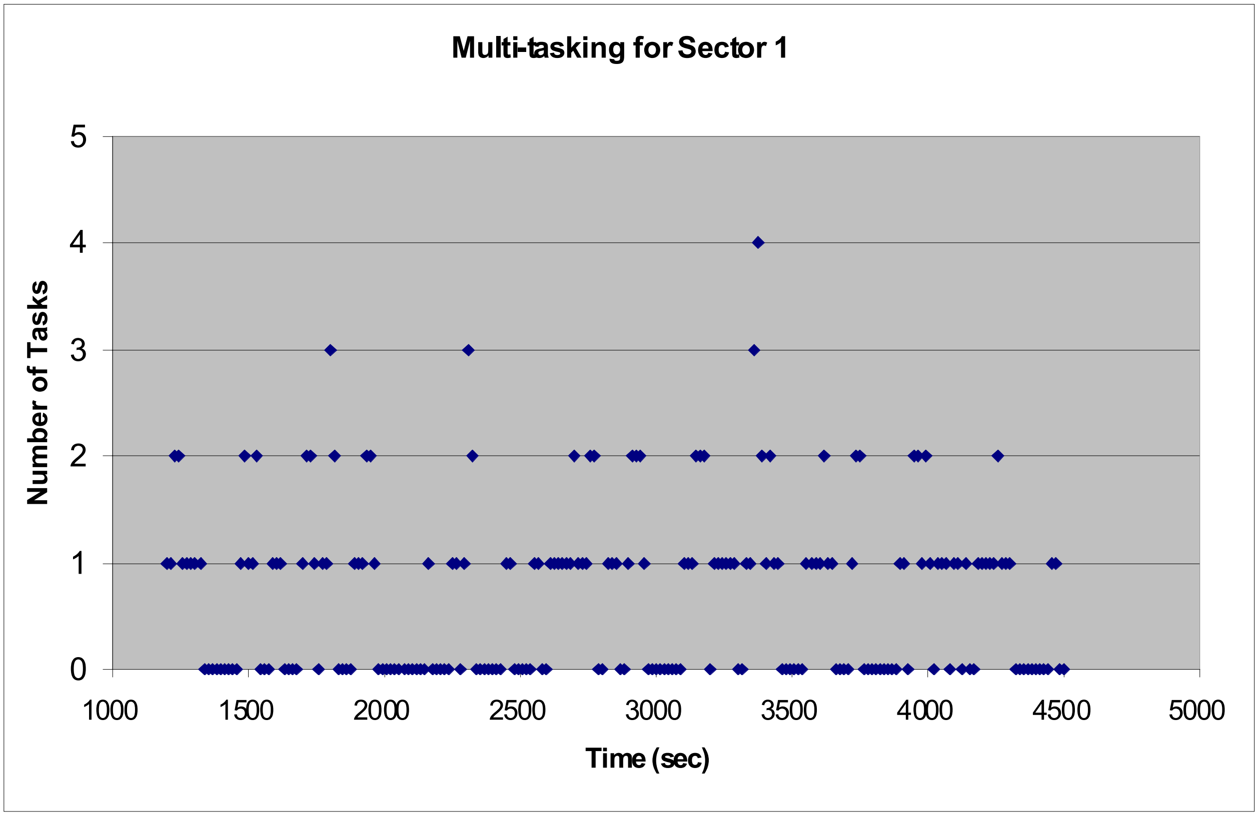
3.3 Model Results

The nominal outputs that the model produces are human performance measures such as task time and workload. For example, the model can predict:

1. The time to complete an activity
2. The number of tasks the controller is performing simultaneously
3. The number of conflicts or spacing/metering problems that the controller has detected in situation monitoring, but hasn't had time to resolve.

The following results correspond to the model executing for 75 minutes of simulation time. Figure 6 depicts the number of tasks that the Sector 1 and Sector 5 R-side controllers were performing during the simulation run. The data in the plot was collected every 15 seconds by taking a “snapshot” of the data element that indicates each task a controller was performing at that instant in time. It is possible that the snapshot might miss an instant when the controller was working on more than the number of tasks indicated by the plot, but since under most circumstances the tasks being modeled require more than 15 seconds to complete, this would be unlikely.

Figure 7 depicts the total time the receiving controller allocated to the handoff process for each receiving handoff that Sector 1 and Sector 5 handled during the simulation run. Because the handoff process requires “waiting for actions” by the transferring controller or the incoming aircraft, the receiving controller is able to use the “waiting” time as an opportunity to work on other tasks. This is an example of multi-tasking.



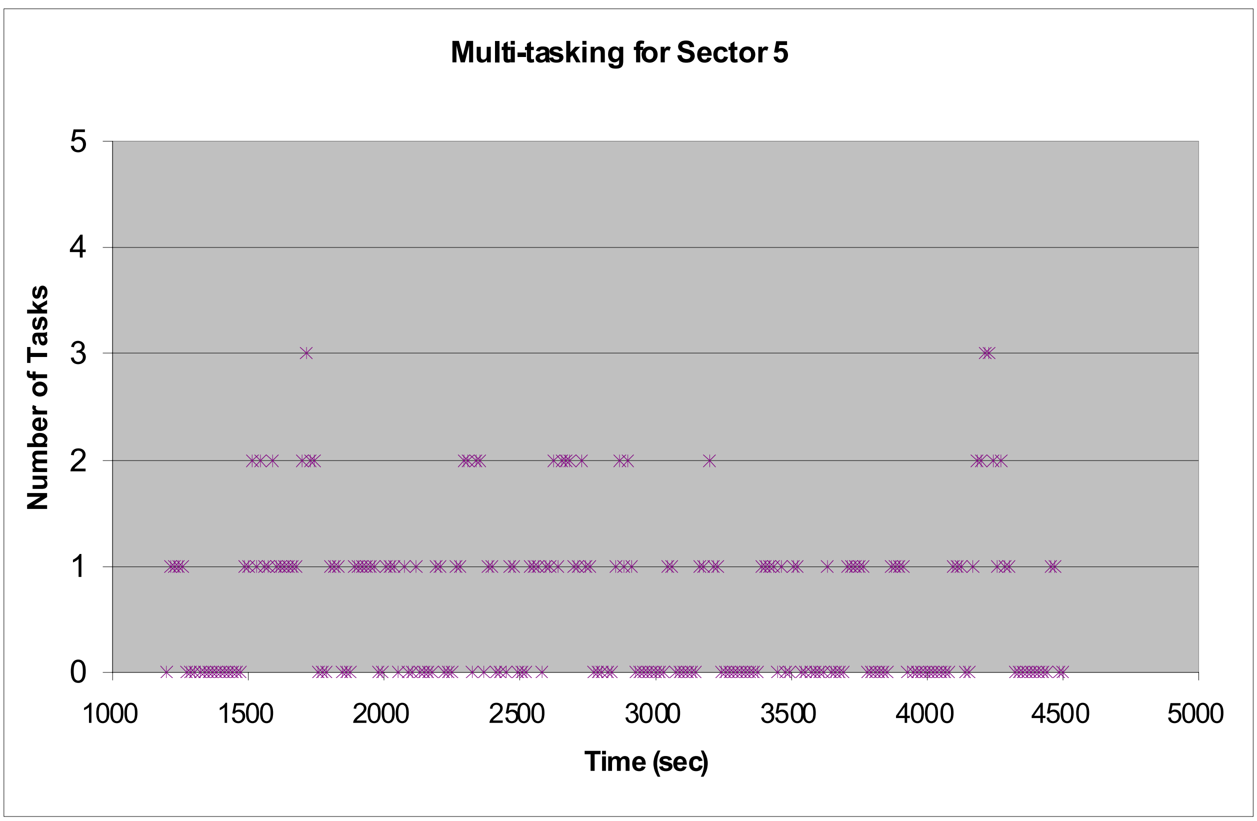
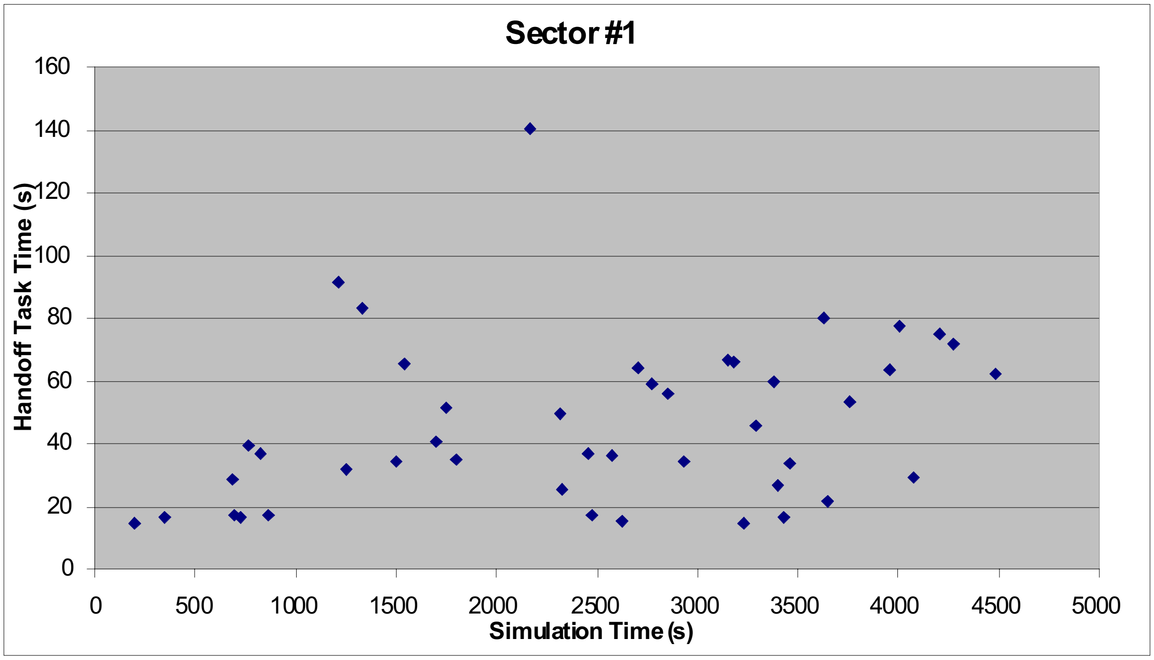


Figure 6. Number of Tasks the R-side Controller is Performing Simultaneously



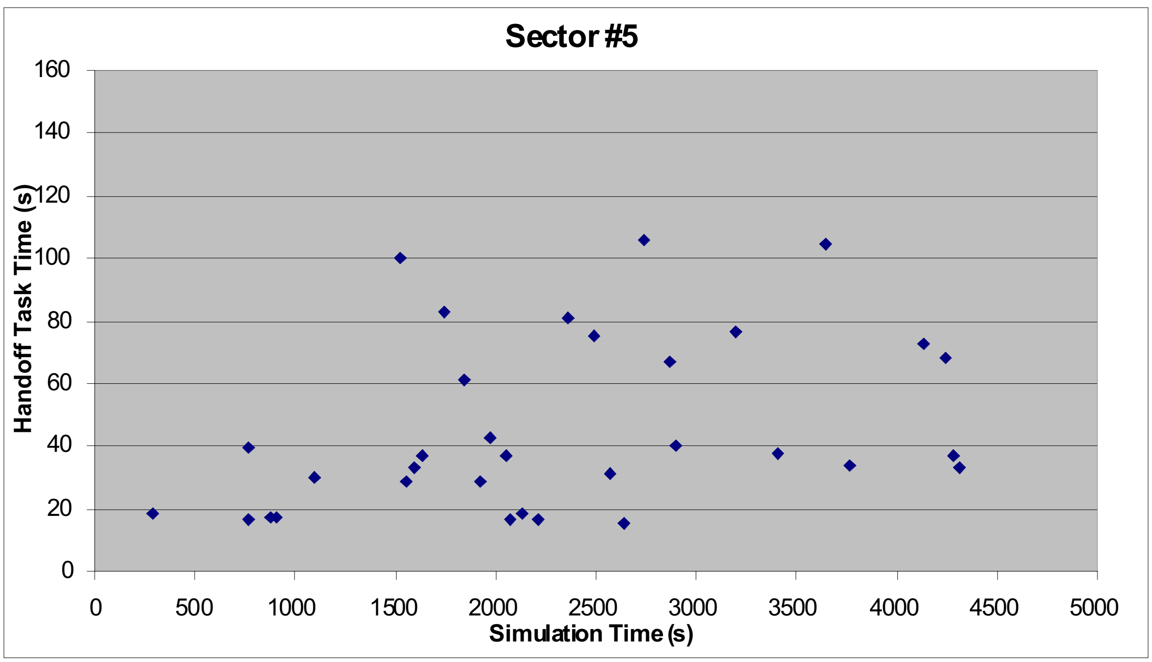


Figure 6. Total Time to Complete the Automated Handoff for the Receiving Controller

4 References

1. *Air Traffic Control Handbook*, 7110.65, FAA, U.S. Department of Transportation.

2. *NAS ATC En route and Terminal Controller/User Operations and Information Processing Tasks*, Computer Technology Associates, Inc., March, 1983.

3. Rodgers, M.D. and Drechsler, G.K., *Conversion of the CTA, Incorporated, En Route Operations Concepts Database into a Formal Sentence Outline Job Task Taxonomy*, DOT/FAA/AM-93/1, Civil Aeromedical Institute, FAA, January, 1993.