Exploring the Many Perspectives of Distributed Air Traffic Management: The Multi Aircraft Control System MACS

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Abstract

This paper describes motivation, design, current and potential future application of the Multi Aircraft Control System (MACS). MACS is a powerful research tool that is being developed at NASA Ames Research Center to increase the overall realism and flexibility of human-in-the-loop air traffic simulations. MACS is designed to enable many participants to be included in the same simulation, on- or off-site. Each MACS station is a platform independent Java program that provides user interfaces and views for pilots, air traffic controllers/managers, airline dispatchers, experiment managers, and observers. Any station can serve as a mid-fidelity input device, an autonomous agent or a display for any perspective of a distributed air traffic management simulation. MACS is laid out for rapid prototyping of user interfaces, air traffic control as well as flight management and guidance functions. Domain and human-factors experts can collaborate with software engineers, quickly prototype new features and operational concepts and evaluate them from different perspectives. In this paper we present some of the currently available views, cover specific research capabilities such as repeatable situation awareness probes, describe the overall simulation layout, and give an example of MACS usage in a Distributed Air Ground simulation study that is currently being conducted at NASA Ames Research Center. Funding for this work was provided by the Advanced Air Transportation Technologies Project of NASA's Airspace Systems Program.

Introduction

Air traffic management research of future concepts needs to address all players including flight crews, air traffic controllers/ managers and airline dispatchers adequately. Interactions between the different stakeholders are among the crucial elements for the viability of a given concept. A simulation capable of addressing this type of distributed decision-making needs to meet several requirements in terms of fidelity, operator proficiency and number of participants. Most research facilities and laboratories can provide a sufficient fidelity for one particular aspect, but lack in the other aspects, because of budget, personnel and proprietary constraints. There are several ways of

addressing the problem of sufficient humans in air traffic simulations, two of which are:

- Include many participants (pilots, controllers, dispatchers) in a given air traffic simulation to work all sides of the problem adequately.

- Include automated agents for side aspects and human participants only for the focus area of the research.

The problem of sufficient fidelity is typically addressed by including specialized facilities that often consist of fielded hard- and software and are therefore costly and difficult to adjust to a particular research setup. Full mission flight simulators, air traffic controller RADAR displays are some examples. These facilities are very important for conducting research in operational environments, and need to be included in simulations.

Several programs have emerged over the past decades providing low- to mid-fidelity air traffic simulations to generate aircraft targets for controller displays that can be controlled by pseudo pilots. Some of these multi-aircraft simulations are frequently used in air traffic research, such as NASA's Pseudo Aircraft System PAS (NASA ARC 2002-A), NLR's Air Traffic Control research simulator NARSIM (NLR 2002), the FAA's Target Generation Facility (FAA 2002), or the ODID based ATC interactive for the future of Air Traffic Control (SKYNET 2002). Additionally even the Internet offers free air traffic control software, e.g. Air Traffic Controller (ATCSIM 2002).

Most of these tools provide custom replicas of ATC displays and relatively simple interfaces for entering pseudo pilot commands. The aircraft dynamics is generated by an internal simulation module and typically permits entering autopilot commands to change heading, altitude and speed of an aircraft.

MACS is not intended to be yet another air traffic control simulator. MACS is designed to be a rapid prototyping environment for operator interfaces and intelligent flight guidance and management functions as well as decision support tools. The idea is to be able to attach MACS stations to existing simulations that combine multi-aircraft target generation facilities, desktop based flight simulators and full mission simulators. Each MACS station offers the same options to observe, participate or evaluate new functions or features. Because MACS is a pure Java program it

is platform independent and can be used on or off-site on windows-based PCs as well as UNIX or LINUX based workstations.

MACS provides a flexible software environment for prototyping, simulating and evaluating air traffic control operational concepts that distribute information and responsibility among controllers, pilots and dispatchers. MACS implements the graphical interfaces for the different types of operators in the same software architecture to allow the design team to readily prototype and evaluate competing operational concepts in real-time.

One Common Situation – Many Perspectives

Experience with distributed air traffic management research shows that much of the same information and similar capabilities are required for pilots, controller, and autonomous agents. All need a common database, aircraft state and performance information, trajectory generation capabilities, event information, etc.

Furthermore, the questions of human automation interaction are very similar for air traffic controllers and pilots. Unfortunately the different parties involved in a distributed decision-making process often only have a very limited understanding of the tasks, tools and information of the other participants.

Therefore, it is a natural step for research purposes to combine all the central information and capabilities in one common core piece and provide multiple views and interfaces to access these core elements. This creates an easy to maintain and modify environment that can rapidly be tailored to particular research needs. It also allows one person to look at a given traffic situation through the eyes of the other person. For example during participatory design a controller issuing a data link clearance can immediately switch to the pilots view and see how the clearance is handled on the flight deck and why it may take longer than expected. A pilot waiting for a new routing may look at the traffic situation from a controller's perspective and understand why it is currently not possible.

MACS Views

MACS currently provides the capability to configure several different views with combinations of individual windows. The six current views are labeled HOME, ATC, PILOT, AOC, CUSTOM and ADMIN. To switch between views the operator clicks on the desired view on the Menu bar and the previously selected configuration is displayed. Available windows are categorized into flight deck displays, ATC displays, aircraft lists, setup windows, analysis windows, internal administration tools, external administration tools and miscellaneous windows.
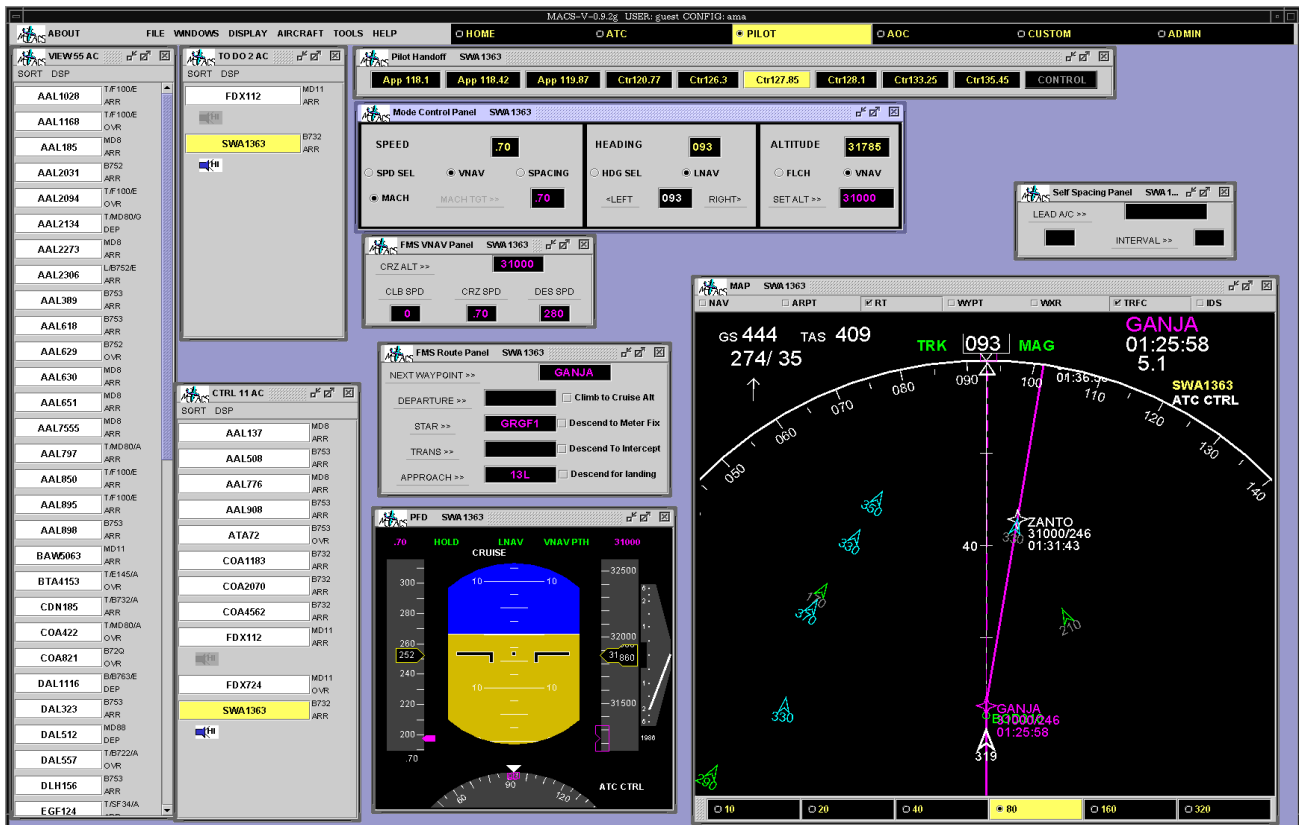

Figure 1: Flight Deck View

Aircraft Lists

MACS maintains a number of aircraft lists that are all accessible to the user. A *main* aircraft list keeps track of all aircraft that are planned for or currently active in the simulation. An *active* aircraft list provides access to all aircraft that are currently flying in the simulation. A *controlled* list maintains all aircraft that are controlled from this particular station, a *view* list contains the remaining active aircraft and a *to do* list keeps track of those aircraft for which an operator action, like a radio check in, or a lower altitude setting are expected.

Flight Deck View

Figure 1 shows a MACS station that gives access to 66 active aircraft, of which this station controls 11 and 55 additional aircraft can be viewed. Two aircraft require the operator's attention and are displayed in the To Do List.

The operator can select any aircraft displayed in any of the aircraft list window or by clicking on the aircraft symbol on the MAP display. He or she can enter basic autopilot commands on the Mode Control Panel and can enter LNAV and VNAV commands on the "FMS Route Panel" and "FMS VNAV Panel". The "Pilot Handoff" panel allows the operator to hand the aircraft to the MACS pilot controlling aircraft on a different frequency.

As stated in the previous paragraphs an important feature of MACS is its ability to allow the design engineers to quickly prototype new guidance functions such as vertical guidance and self-spacing functions and the complementary air and ground displays to evaluate new Air Traffic Control concepts. The Self Spacing Panel in the upper right is one example for making a research function easily selectable for operators, so that it can be used for many aircraft in a given simulation.

MACS can provide reminders to the operators when actions must be taken. The icons in the aircraft lists in figure 1 are examples for those reminders prompting the operator to check in. Other reminders include lowering the MCP altitude or entering a STAR transition or an approach routing. A MACS station can also be run in an automatic mode where, instead of reminding the operator, the actions are performed automatically. This function allows us to run prototype concepts with automatic pilot-agents for controller display development, scenario development and controller training, or to automate those parts of the airspace that are outside the immediate subject area.

ATC Views

For future simulations within the Airspace Operations Laboratory (AOL) at NASA Ames Research Center, MACS will provide some of the controller stations with ATC plan view displays that closely resemble the look and
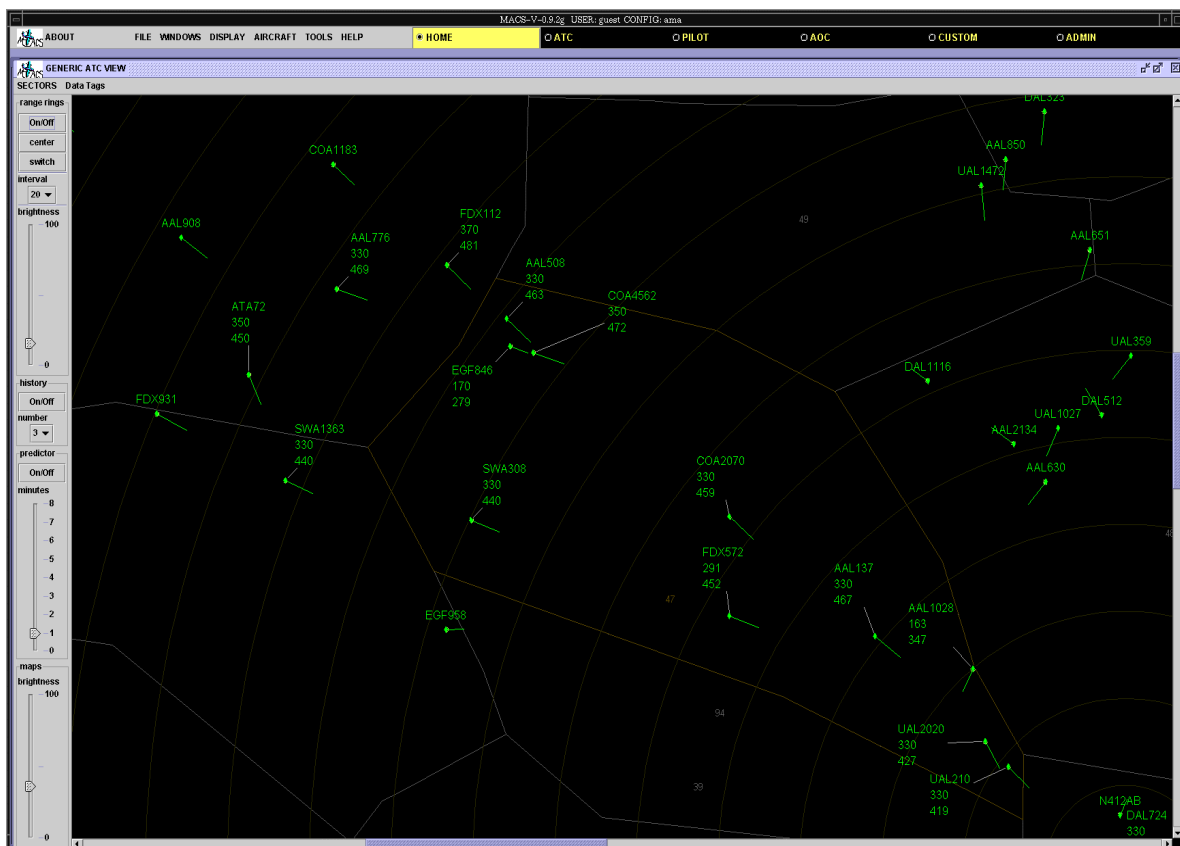

Figure 2: Generic ATC View

feel of fielded ATC displays. Generic ATC displays are integrated for rapid prototyping of more advanced functions. At this time (June 2002) a MACS STARS view as well as a DSR (Display System Replacement) view are prototyped and a generic ATC view is available as well as data tag configuration panels.

Operator Support and Autonomous Agent Functions

The core piece of supporting the operator or acting as an autonomous agent is the event controller imbedded in each MACS station. This event controller periodically checks all aircraft in the simulation for a number of easily specified events that require an operator action. An event control setup panel allows the experimenter to select whether to prompt the operator or to perform the event automatically. The settings can vary by aircraft category (arrival / over flight / departure) or by a specific research status such as whether an aircraft is a free-flight or ATC controlled. Figure 3 depicts the initial event control panel.

Situation awareness probes

This event control mechanism is also used to run situation awareness probes. These probes are used to cause aircraft to misbehave in a certain manner, for example by leaving the assigned altitude early, turning away from the current route or increasing / reducing speed. These types of probes can be used to test a controller's situation awareness in a repeatable manner. The probe control panel allows the experimenter to specify the aircraft callsign, the type of misbehavior, the enabling condition that causes the probe to fire, the duration of the probe, and the action that is taken, when the probe is completed. When a probe is launched the respective control component on the Mode Control Panel for that particular aircraft indicates that the speed, heading, or altitude are currently controlled by the probe settings. When the controller detects the misbehavior and issues a new command to the pseudo pilot or asks for his or her intentions, the pilot turns off the probe. The time between launching the probe and turning it off can be used as one indicator for the controller's awareness of the current situation. Probes like these have been suggested for example by (Pritchett, Hansman and Johnson, 1995) and (Durso, Hackworth and Truitt, 1999).
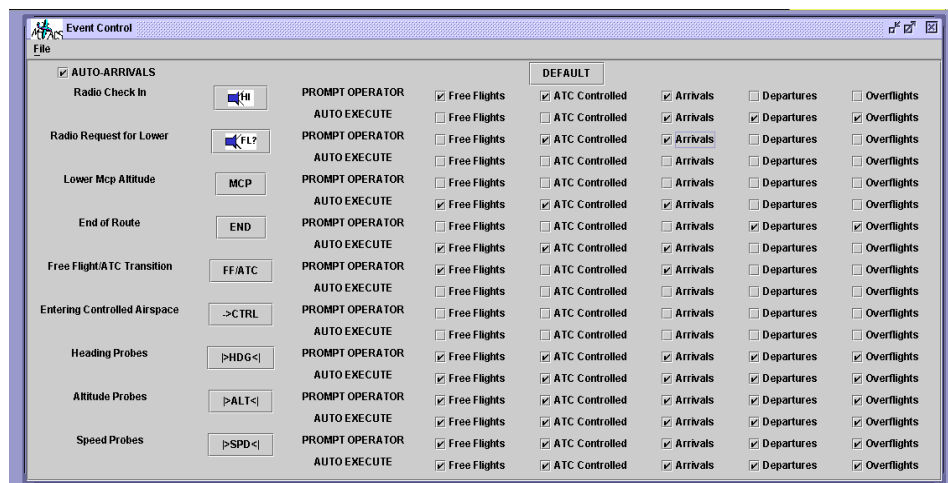

Figure 3: Event Control Panel

Process and simulation monitoring

MACS is a multi-threaded software program. Each window and each periodic function, like aircraft guidance, event controlling, message handling, or data collection are updated by it's own thread. A thread observer, which is a thread itself, monitors the health of all other threads and restarts any one that appears to have encountered a software problem. The internal status of all threads including current update rate is displayed and can be controlled through a Thread Control Panel. This makes this complex software robust and prevents the need for restarts.

Each station is typically part of a multi component simulation, which can include many other MACS stations flight simulators, target generation facilities, etc. The status of any major connection inside a simulation is reported to each MACS station and can be visualized through a process control window. This allows the experimenter to monitor which components are already connected and whether the communication occurs in a timely manner. This information can be crucial for conducting large-scale simulations.
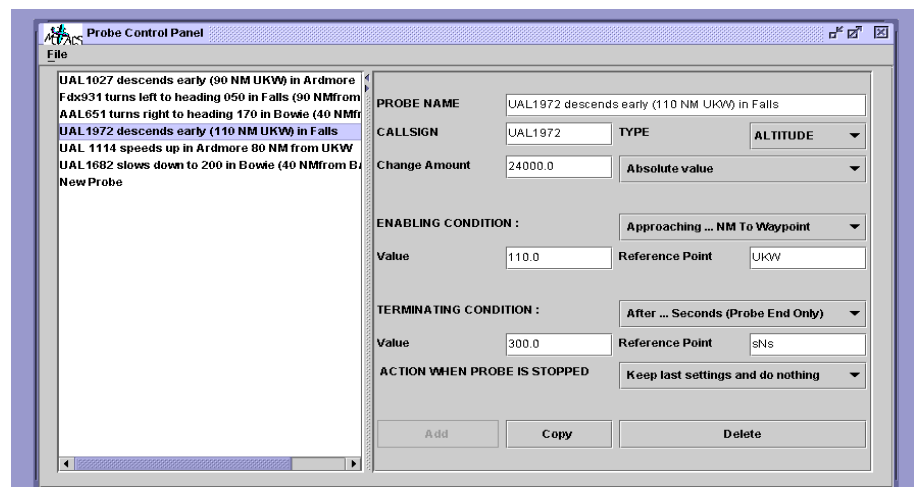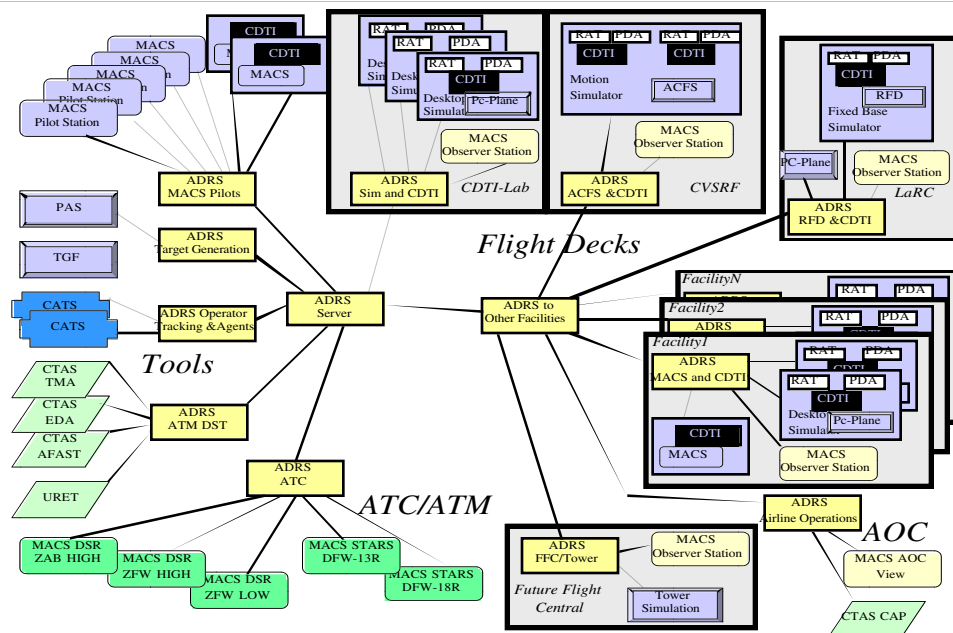

Figure 4: Probe Control Panel

Figure 5: Planned Simulation Architecture (Prevot et al. 2002)

Simulation architecture

MACS stations play an increasing role in future Distributed Air Traffic Management simulations in the Airspace Operations Laboratory at NASA Ames Research Center. Figure 5 shows the planned software architecture for upcoming studies. Each MACS process runs on a separate computer. Each pilot station controls selected aircraft according to its configuration. The MACS STARS stations will provide the displays for TRACON sectors. The MACS DSR stations will provide the displays for en route sectors.

All MACS stations connect to the Aeronautical Datalink and Radar Simulator (ADRS). The ADRS serves as an information hub for the simulation. It receives state and trajectory information from aircraft simulators, aircraft control and guidance information from pilot stations and Cockpit Displays of Traffic Information (CDTI) and controller inputs and decision support advisories from CTAS systems. It validates, stores, and processes the data and distributes the requested information among its servers and clients. Multiple ADRS processes run simultaneously, share their information, and provide access to all simulation data. This allows for adding many processes at different ADRS nodes without impacting the real-time performance. This general simulation architecture is already in place and used. However, the MACS controller displays are currently under development and expected to be used by the end of 2002. Meanwhile the AOL continues to use the CTAS Plan view Graphical User Interfaces as the primary controller interface. More information on the ssimultaion architecture can be gathered at (NASA ARC 2002-B) and (Prevot et al. 2002).

MACS usage in DAG-TM experiment

We currently conduct an air-ground integration experiment in the AOL at NASA Ames Research Center that compares a sector-oriented approach of handling arrival traffic to a trajectory-oriented approach within the framework of the Distributed Air Ground Traffic Management (DAG-TM) program. The simulation combines airborne FMS capabilities with CTAS decision support tool functions (Erzberger, 1995; Green and Vivona, 1996) and data link. Four teams with five subject controllers per team work four different high and low altitude sectors and one traffic manager position. Three confederate controllers handle ghost Center and TRACON positions

Following up on earlier studies (Prevot et al., 2000; Callantine et al., 2001) the study measures performance impacts as well as effects on controller workload and situation awareness of an operational concept for flying FMS trajectories in Center and TRACON Airspace (Palmer et al., 1999). Eight to ten pseudo pilots use MACS stations to control approximately eighty aircraft per simulation run. An additional MACS station acts as autonomous agent to land arriving aircraft and maintains control over departures and overflights that have been handed off to uncontrolled sector positions.

In some of the simulation runs pre-defined situation awareness probes are injected as described above. Additional MACS stations configured only for viewing the situation provide quick-look data analysis and on-line simulation health status information to the experimenters.

Other applications

In addition to its role as an integrated component of the DAG-TM architecture work is underway to use MACS for rapid evaluation of intelligent flight guidance functions, decision support tools and operator activity models. Different control laws for vertical navigation or spacing functions are centrally implemented. We evaluate system performance as well as human machine interaction considerations on the flight deck and the air traffic control room. Advanced Required Time of Arrival capabilities are integrated and made available to pilots and controllers at the same time to determine the benefits and problems of advanced decision support automation in early design stages. Air traffic controller and pilot activity models will manage aircraft autonomously, provide support to the human operators, and give insights into expected and actual operator behavior.

Summary and future work

At this time (June 2002) the MACS pilot interfaces, flight guidance functions, event controllers and probe controllers are fully operational and initial prototypes for the ATC displays have been developed. The overall development to this point took less than eight months for a few developers. This is a good indication of the rapid prototyping potential that the chosen approach offers. We will continue integrating more interfaces and functions into the architecture. We will also start integrating pilot and controller models for activity tracking or more intelligent autonomous behavior.

In addition to the in house use, we also plan to distribute MACS stations to other research facilities in order to participate in our simulations or for use in their own laboratories. Ideally other researchers and developers can contribute and integrate additional displays, agent models or other capabilities that enhance the versatility of this research tool.

Acknowledgements

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