ASC: 02-1556

To appear in, *Proceedings of the 46th Annual Meeting of the Human Factors & Ergonomics Society,* Baltimore, MD, 30Sep –4 Oct, 2002.

USING SOFTWARE AGENTS IN A WORK CENTERED SUPPORT SYSTEM FOR WEATHER FORECASTING AND MONITORING

Ron Scott
BBN Technologies
Eden Prairie, MN

Emilie M. Roth
Roth Cognitive Engineering
Brookline, MA

Stephen E. Deutsch
BBN Technologies
Cambridge, MA

Erika Malchiodi
BBN Technologies
Cambridge, MA

Tom Kazmierczak
BBN Technologies
O'Fallon, IL

Robert G. Eggleston
Human Effectiveness Directorate
Air Force Research Laboratory
Wright-Patterson, AFB, OH

Samuel R. Kuper
Human Effectiveness Directorate
Air Force Research Laboratory
Wright-Patterson, AFB, OH

Randall Whitaker
Northrop Grumman Information Technology
Dayton, OH

There has been a growing interest in developing system architectures and human-software agent interaction paradigms that deploy software agents in the service of effective support for human task performance. This paper describes an agent-based system for a weather forecasting and monitoring application, called *Work Centered Support System for Global Weather Management (WCSS-GWM*), that takes this approach. *WCSS-GWM* exemplifies and extends Cognitive Engineering (CE) principles for effecting human-software agent interaction and Work Centered Support System (WCSS) concepts. Two fundamental CE principles are *observability* and *directability*. Users need to be able to 'see' what the software agents are doing and be able to re-direct the software agents as task demands change. The WCSS brings an additional, complementary perspective, emphasizing the need to support the multiple facets involved in individual cognitive and collaborative work (decision-making, product development, collaboration, and work management). The WCSS-GWM agent-based architecture is explicitly designed with these objectives in mind.

Introduction

There has been increasing interest in the development and integration of software agents into decision support systems (Jennings & Wooldridge, 1996; Sycara, 1998). The literature on software agents has stressed the high-level tasks that are delegated to agents, the degree of autonomy that the agents are granted in carrying out their tasks, and the dynamically changing environments in which agents operate (Jennings & Wooldridge, 1996).

Recently, there has been a growing interest in developing system architectures and human-software agent interaction paradigms that deploy software agents in the service of effective support for human task performance (Chistoffersen and Woods, in press; Lenox, Hahn, Lewis, & Roth, 1999; Malin, 2000; Malin, Johnson, Molin, and Schreckenghost, 2002). This paper describes an agent-based system we are developing for a weather forecasting and monitoring application that takes this approach. The emphasis has been on developing an agent-based system architecture and application that exemplifies and extends principles for effecting human-software agent interaction.

The agent-based system is being developed as part of a larger program focused on development of principles and tools for Work Centered Support Systems (Eggleston and Whitaker, 2002; Eggleston, Young and Whitaker, 2000; Young, Eggleston and Whitaker, 2000). A Work Centered Support System (WCSS) is a software application that employs both direct and indirect work aiding and integrates four types of work support: 1) *Decision Support*- aiding problem solving and other cognitive processes in the process of work; 2) *Product Development support*- direct aiding of the production of the deliverable artifact(s) of work; 3) *Collaborative Support*- aiding team and colleague interactions in work, and 4) *Work Management Support*- aiding the meta cognitive activities entailed in prioritizing and managing multiple interweaved tasks that arises in work. A key element of the work centered design is supporting the work through structural form design principles that act as indirect aids. The agent- based system, called Work Centered Support System for Global Weather Management (WCSS-GWM), is intended to exemplify all four types of work support and both direct and indirect aiding.

Understanding the Demands Imposed by the Domain of Work

The system is being developed to support weather forecasting and monitoring in an airlift service organization.

The particular focus has been on weather forecasting in support of planning and managing airlifts, both pre-flight and en route. A Flight Manager (FM) has primary responsibility for planning and managing a flight. Since weather can have important impact on pre-flight and en route flight management decisions (e.g., there may be a need to accelerate, delay or re-route a flight due to unfavorable weather conditions), weather forecast staff work closely with the FM to evaluate weather conditions at the take-off and landing airfields as well as through the planned flight corridor.

A cognitive work analysis (CWA) has been an integral part of the WCSS-GWM development process (Vicente, 1999). A series of site visits were scheduled to observe and interview FM and weather forecasters. These CWA activities served to reveal the demands imposed by the domain of work, and identify what aspects of cognitive and collaborative work could most benefit from decision support, as input to the design of the WCSS-GWM architecture and displays.

The WCSS-GWM development team was able to observe the FMs and weather forecasters engaging in planning and en route monitoring of flights. This included observation of the detailed process by which weather forecasters review and integrate multiple weather sources in preparing weather forecasts and monitoring changes in weather, as well as the process by which they prepare weather products as input to the pre-flight packages that the FMs create and send to the airlift pilots several hours prior to flight (called "crew papers").

Observations spanned both routine cases as well as challenging cases that revealed the intense collaboration between FMs and weather forecasters that occurs when weather conditions (e.g., severe turbulence; lack of anticipated tail wind) require modification to planned flight routes (either pre-flight or en route).

The CWA revealed that the flight managers and weather forecasters operate closely as a team to manage the airlift missions in their work queue. The flight manager is the prime player, constructing flight plans, preparing crew papers, and monitoring the many details involved in ensuring the success of each mission. Weather forecasters maintain broad situational awareness of weather conditions in the multiple world regions of interest, prepare general forecasts for different regions of the world as well as tailored forecasts for each mission, and monitor newly available weather observations to assess their impact on current and upcoming missions. Unexpected occurrences in either domain (flight management or weather), are quickly attended to by both team members, to better understand the effects of the changing situation and determine appropriate action (e.g., delay a flight, reroute a flight, make changes to the planned fuel load or cargo).

Initial design for a Global Weather Management WCSS

The results of the CWA revealed a number of opportunities to support weather forecast and monitoring work as part of a complete WCSS. This included:

- Providing support to weather forecasters in their role of developing weather forecasts and weather products by integrating information from multiple weather sources, including real-time weather updates, on a geo-referenced map (*product development support*)
- Enabling the weather forecasters to more rapidly recognize changes in weather conditions and update/refine forecasts (*decision support and product development support*). Currently the process by which weather forecasters develop and revise forecasts is labor intensive and therefore forecasts are not updated as often as they would like. Tools that enable more rapid recognition and dissemination of changes in weather conditions from what was earlier forecasted would enhance forecast accuracy and timeliness.
- Supporting the weather forecaster/FM *team* in evaluating the impact of weather on flight plans (both pre-flight and en route) and making re-route decisions by:
    - superimposing the flight plan, organized tracks and weather data on a single geo-referenced map to allow the team to directly visualize the impact of weather on a flight route (*decision support and collaboration support*)
    - providing notification of missions that are impacted by changes in weather (*work management support*)

The WCSS-GWM was designed to illustrate a WCSS approach by providing this support. The WCSS-GWM is primarily intended to support the weather forecasters, but it is also intended to be useful to FMs in assessing weather conditions and their potential impact on upcoming or en-route flight missions.

To meet these design objectives, the WCSS-GWM required the following functionality:

- Acquisition of real-time weather observations, such as PIREPS (pilot reports) and ACARS (aircraft communication and reporting system)
- Acquisition of worldwide airfield and upper air forecasts produced both locally and remotely (e.g., TAFs, METARS, SIGMETS)
- Visual integration of multiple data sources – map, flight plans, forecasts, point observations, satellite imagery. An important design requirement was the ability to easily overlay any subset of these on the same geo-referenced map for purposes of comparison.
- Automated comparison of real-time weather observations with previously-made forecasts, and generation of alerts to focus user attention on operationally relevant changes in weather conditions
- Automated and directed monitoring of individual missions and geographical areas of interest, and

generation of alerts to focus user attention on changes in weather conditions that can impact planned or en-route flights

The demonstration prototype combines computer generated flight plans and weather information on a map based, geo-referenced display. Figure 1 shows a screen shot from the WCSS-GWM that illustrates the basic features of the WCSS-GMW.

The "home view" of the WCSS-GWM is a map showing the geographical area of interest, with a number of controls arranged around the map.

Standard map controls let the user pan and zoom and change projections. Layer controls allow multiple layers of flight and weather information to be viewed on the map. Flight plans, PIREPS, ACARS, observations, SIGMETs, satellite images, layers that can be placed on and taken off from the map. An altitude slider control allows the user to filter observations by specifying an altitude area of interest. More details can be accessed by hovering over an icon. For example, the text of a PIREP can be obtained by placing the mouse over the PIREP symbol displayed on the map.

A floating Sortie Palette provides an overall summary of all missions of interest, status of individual missions, the ability to highlight and locate specific missions, and the ability to sort and organize them to suit the work context. It also provides work organization aiding that enables users to maintain awareness of which alerts have and have not been viewed.

An important feature of the WCSS-GWM is that it includes software agents that monitor missions and watch areas, and provide notification when operationally significant changes in weather arise. A key design element of the WCSS-GWM is that these software agents can be created, monitored, and modified by the user. For example, the user can create an agent by drawing a polygon around a region of interest on the map and specifying the agent behavior (desired altitude, start and stop time, hazard type and severity to watch for). At a later time the user can modify the agent behavior by changing these parameters, as well as modify the shape and position of the polygon. Figure 2 shows a screen shot from the WCSS-GWM that illustrates the ability to create and modify agents.

How Do Agents Fit In?

While the literature on software agents has tended to focus on the high level tasks that are delegated to agents and their level of autonomy, the value of agent technology from a software development perspective is that software agents are small, independent 'chunks' of software that each address a small unified set of tasks, are separately controllable, and separately modifiable.

In creating the agent architecture, a key consideration has been to structure the software so that the capabilities of the software 'chunks' implemented as agents will be meaningful to the user in domain terms. This applies both with respect to the functions that they perform (acquire data, analyze data, present data) and to the domain objects that the software agents work on (e.g., missions, forecasts, watch areas). Once the software is organized into domain meaningful 'chunks' implemented as software agents, users can more readily observe and direct their operation. It then becomes possible to consider how the software agents can collaborate among themselves and with the users in accomplishing the four aspects of WCSS work (decision-making, product development, collaboration, and work management).

WCSS-GWM agent-based system, based on D-OMAR (Deutsch, Cramer, Keith, & Freeman, 1999), contains three classes of agents:

- **Acquisition Agents** –acquire data from outside sources (e.g., WX bulletins, ACARS, SIGMETs, satellite imagery, mission details, flight plans)
- **Analysis Agents** - analyze data retrieved by acquisition agents to produce initial problem indications (individual turbulence reports, intersections of flight plans with SIGMETs, …). Types of analysis agents include:
  - *Forecast analysis agents* that are triggered by the weather forecasters as they create their weather forecasts. These agents look for information supporting that forecast
  - *Region analysis agents* that are triggered by the weather forecasters when define geographic 'watch areas'. These agents watch for observations matching forecaster-defined criteria
  - *Mission analysis agents* – these are automatically generated by the presence of a current or upcoming flight mission. This agent watches for reports (e.g., PIREPS or ACARS, SIGMETs) close to (in latitude, longitude, altitude, time space) that would significantly affect the mission
- **Presentation Agents** - based on the results of the analysis agents, these agents decide what information is presented to the user. These agents work on initial problem indications, clustering and prioritizing, to present high-level presentation of problems. For example, there may be many related "notifications" generated by the analysis agents that need to be aggregated together into a single 'notification' message to avoid an 'alarm avalanche' problem (Woods, 1995). Similarly, in a full-scale implementation of a WCSS-GWM these agents would also be responsible for knowing which of the several flight managers or weather forecasters currently on shift would be interested in which information.

Cognitive Engineering and WCSS Exemplified by the WCSS-GWM

The WCSS-GWM exemplifies and extends cognitive engineering and WCSS principles for the deployment of software agents in support of human work.

A growing body of Cognitive Engineering literature has shown that in order for automated agents to be effective they must act as 'team players' (Roth, Malin & Schreckenghost, 1997; Malin, 2000; Christoffersen and Woods, in press). For software agents to become team players, there are two fundamental characteristics that need to be designed in from the beginning – *observability* and *directability*. Users need to

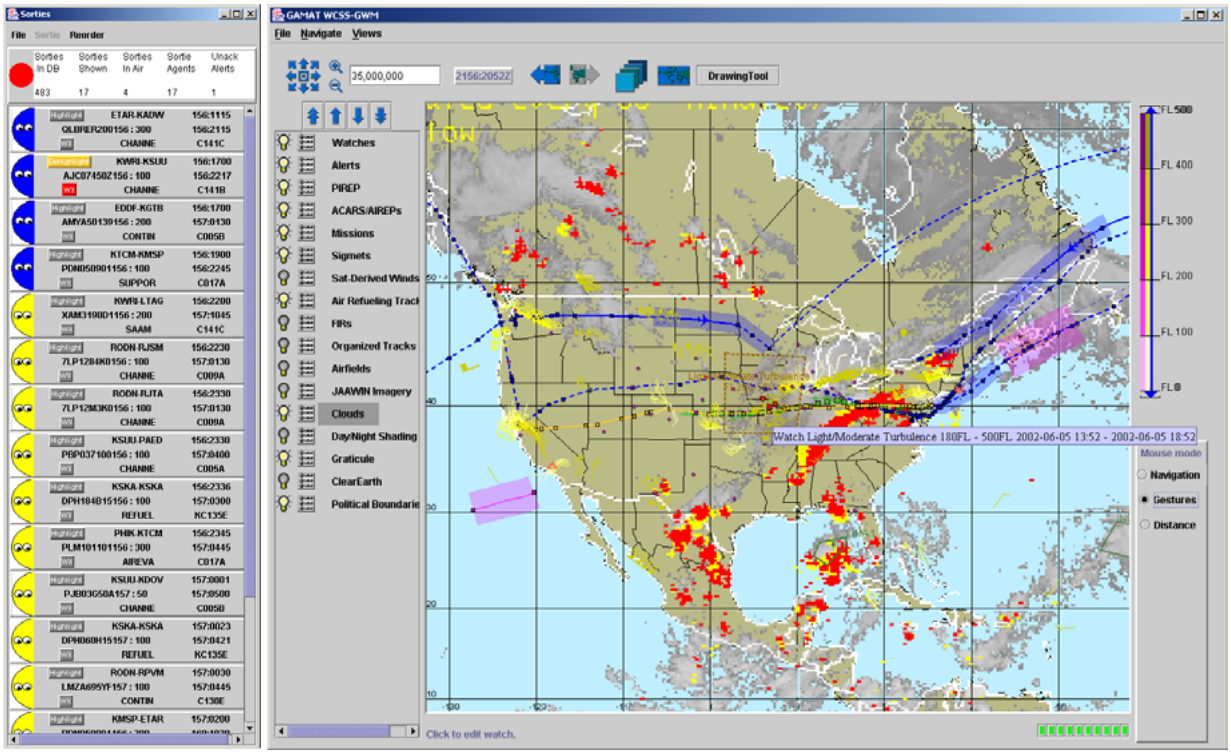

Figure 1. A screen shot from the WCSS-GWM that illustrates the basic features of the WCSS-GMW. Layer controls allow multiple layers of flight and weather information to be viewed on a map. A floating Sortie Palette (window on the left) provides summary status of individual missions, and allows users to highlight and locate specific missions on the map. It also enables users to maintain awareness of alerts that have been generated by agents, and whether they have been viewed.

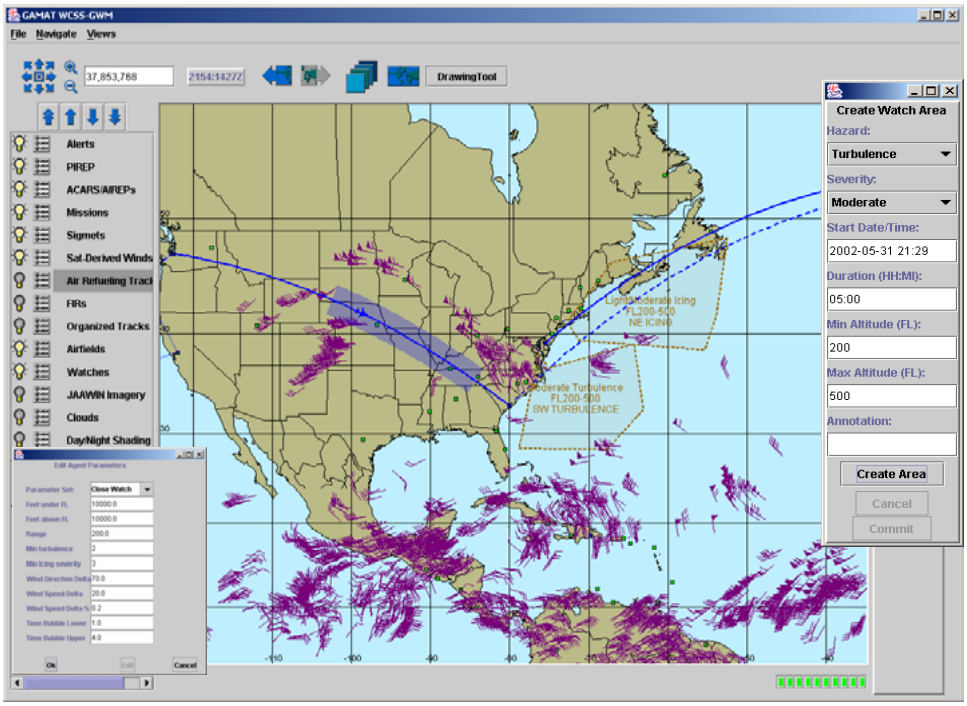

Figure 2. shows a screen shot from the WCSS-GWM that illustrates the ability to create and modify agents.

be able to 'see' what the automated agents are doing and understand what they will do next relative to the state of the task. A principle that has emerged in both the human communication /collaboration literature as well as the autonomous software agent literature is the need for a shared representation of the problem state ('common ground') to support communication and coordination. This requires both human and software agents to perform their tasks through a common interface where each works with the same representation of the important information. Humans also need to be able to control and re-direct the software agents as task requirements change.

The WCSS-GWM agent-based architecture is explicitly designed with these objectives in mind. The geo-referenced map with weather and flight information superimposed provides a shared representation (common ground) of the current situation that is available to the multiple humans (FMs as well as weather forecasters) and software agents involved in interpreting weather and it's implications for flight missions. Furthermore, the activities of the agents are directly visible and controllable by the users. For example, the geographic area being monitored by the software agents (both with regards to a flight mission and with regards to forecast and watch areas) are explicitly presented on the display and can be modified by the user. Similarly the weather parameters being monitored by the agents and the trigger points for alerts can be inspected and modified by the user.

The WCSS brings an additional, complementary perspective to the design of decision-aiding software. In particular, it emphasizes the need to support the multiple facets involved in individual cognitive and collaborative work. This includes consideration of not only the problem-solving/decision-making aspect of work, but also the activities involved in creation of work products, the processes entailed in collaborative work, and the cognitive effort involved tracking and management of multiple intertwined work activities (e.g., requirements for attention shift and memory of the number and state of tasks in process). The WCSS-GWM agent-based architecture and user interface modules are explicitly designed to support all these aspects of work.

The WCSS-GWM is currently in the development phase. The development process has involved tight design iterations that have included user review of rapid prototypes. User feedback to date has been extremely positive. Comments from both the forecast and flight management communities have confirmed the validity of the cognitive analysis and suggest that the WCSS-GWM should improve the quality and timeliness of weather-related flight mission support.

More formal, person-in-the-loop tests are currently being planned to more systematically evaluate the benefits of the Cognitive Engineering and WCSS design approach.

References

Christoffersen, K. & Woods, D D. (in press). How to make automated systems team players. In E. Salas, (Eds.) *Advances in Human Performance and Cognitive Engineering Research*, Volume 2. JAI Press/Elsevier.

Deutsch, S. E., Cramer, N. L., Keith, G., & Freeman, B. (1999). *The distributed operator model architecture (D-OMAR).* Report No. AFRL-HE-WP-TR-1999-0023. Wright-Patterson AFB, OH: Air Force Research Laboratory.

Eggleston, R. G. & Whitaker, R. D. (2002). Work Centered Support Systems Design: Using Organizing Frames to Reduce Work Complexity. *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting).* Santa Monica, CA: Human Factors and Ergonomics Society.

Eggleston, R.G. , Young, M. J. & Whitaker, R. D. (2000). Work Centered Support System Technology: A New Interface Client Technology for the Battlespace Infosphere. *Proceedings of NEACON 2000, Dayton Oh, 10-12 October, 2000* ,pp 499-506.

Jennings, N. & Wooldridge, M. (1996). Software agents. *IEE Review,* January 1996, 17-20.

Lenox, T., Hahn, S., Lewis, M. & Roth, E. M. (1999). Improving performance: Should we support individuals or teams? *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting (pp. 223-227).* Santa Monica, CA: Human Factors and Ergonomics Society.

Malin, J. (2000). Preparing For The Unexpected: Making Remote Autonomous Agents Capable Of Interdependent Teamwork, *Proceedings of the XIVth Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Society (pp. 1-254 - 1-257).* , Santa Monica, CA: Human Factors and Ergonomics Society.

Malin, J. T., Johnson, K., Molin, A. & Schreckenghost, D. (2002). Integrated Tools for Mission Operations Teams and Software Agents**.** *IEEE Aerospace Conference Proceedings (CD),* Big Sky, Montana, March 2002.

Roth, E. M., Patterson, E.S. & Mumaw, R. J. (2002). Cognitive Engineering: Issues in User-Centered System Design. In J. J. Marciniak (Ed.), *Encyclopedia of Software Engineering*, 2nd Edition (pp 163 – 179). New York: Wiley-Interscience, John Wiley & Sons.

Roth, E., Malin, J.& Schreckenghost, D. (1997). Paradigms for intelligent interface design. In M. Helander, T. Landauer, & P. Prabhu (Eds.), *The Handbook of Human-Computer Interaction. 2nd Completely Revised Edition* (pp. 1177-1201). Amsterdam: Elsevier.

Sycara, K. (1998). Multiagent systems. *AI Magazine*, *19* (2), 79-92.

Vicente, K. J. (1999). *Cognitive work analysis: Towards safe, productive, and healthy computer-based work*. Mahwah, NJ: Erlbaum.

Woods, D. D. (1995). The alarm problem and directed attention in dynamic fault management. *Ergonomics*, 38(11), 2371-2393.

Young, M.J. , Eggleston, R. G. & Whitaker, R. D. (2000). Direct manipulation interface techniques for interaction with software agents. Paper presented at the NATO/RTO Symposium on Usability of Information in Battle Management Operations, Oslo, Norway, April 2000.