Modeling and Simulation for Work System Design

Maarten Sierhuis
USRA/RIACS
NASA Ames Research Center
Moffett Field, CA 94035
msierhuis@mail.arc.nasa.gov

Introduction

Work systems are systems in which humans, computer, robotic, and other systems, artifacts, and space come together performing activities over time to produce goods, services or, as is the case in the work system described in this paper, scientific discovery. The work systems we encounter everyday have mostly existed over a long period of time. Improvement of such work systems is often done through business process analysis and reengineering (Hammer and Champy, 1993) (Davenport, 1993). Seldom do we face the design of a work system that does not exist. In this paper we describe the initial design of a work system that does not yet exist. The work system to be designed is a mission operations system for a proposed NASA discovery mission to the Moon with a semi-autonomous rover.

The use of M&S in work system design

Due to the continued increase of computing power, many engineering disciplines now make use of powerful computational modeling and simulation (M&S) tools. The benefit of computational modeling is that it allows for the creation of virtual prototypes of the designed system. On top of this, computer simulation allows us to investigate the behavior of a virtual prototype, and thus understand the strengths and weaknesses of the design of the system over time. Using M&S is particularly effective when the complexity, time and cost of creating and testing a design of a system with real-world physical prototypes, is extremely high (Zeigler et al., 2000). M&S of work systems falls in this category.

The complexity and cost of creating a real-world simulation of a work system is extremely high. We claim that using the Brahms tool in the design process of work systems allows us to test work system designs that could not easily be tested before its actual implementation and operation. In high-risk NASA missions such a capability would be extremely useful. This obviously has a huge potential in helping to solve one of the most often cited causes in NASA mission failures [ref. Challenger accident report and Mars Polar Lander failure report].

Work Practice

Often people view work merely as the process of transforming input to output, i.e. a Tayloristic view of work. In contrast, a work practice is defined as the collective activities of a group of people who collaborate and communicate, while performing these activities synchronously or asynchronously (Clancey, 1998). We are interested in describing work as a practice, a collection of psychologically and socially situated collaborative activities between members of a group. We try to understand how, when, where, and why collaborative activities are performed, and identify the effects of these activities, as well as to understand the reasons why these activities occur in the way they do. Therefore, the central theme is to find a representation for modeling work practice. Brahms is a M&S environment for representing a work process at the work practice level using a multiagent rule-based activity language, that can be simulated using the Brahms simulation engine (Sierhuis, 2000) (Sierhuis et al., 2000b) (Sierhuis et al., 2000a).

This paper discusses how we have used Brahms to design the work system for the proposed Victoria mission. The attentive reader might question how we can *design* a work practice? Indeed, a work practice is not designed. Instead, it evolves over time. However, what we are interested in studying is how a model of the design of a work process at the practice level, can be used in the design of the mission. We believe that a model at the work practice level allows us to represent the future work system in a more realistic manner, because it takes a holistic approach to the representation of work (Clancey et al., 1998) (Clancey, 1997a) (Clancey, 1997b) (Sierhuis and Clancey, 1997). It represents individual agent behavior, group behavior, and collaboration, as well as the use of tools, artifacts and where they are located during the actual work. This is in contrast to other work process and knowledge modeling paradigms (Tyo, 1995). Next, we discuss the Victoria case study.

Victoria Mission

Victoria[1] is the name of a proposed long-term semi-autonomous robotic mission to the South Pole region of the Moon. At the start of this case study the Victoria team was in the middle of writing the proposal. Team members (so called Principal Investigator and Co-Investigators) of the Victoria mission are world-renowned scientists from different scientific disciplines (planetary scientists geologists, robotisists, and AI-specialists).

From this scientifically important objective, the Victoria team decided that the most efficient way to meet this science objective is to use a high-speed semi-autonomous rover that can traverse over long distances (several hundreds of kilometers), for a long time period (three months to a year), to gather the necessary geological and physics data (Cabrol et al., In press) (Spudis, 1999).

The Victoria Rover

The Robotics Laboratory at Carnegie Mellon University is developing the Victoria Rover. One of the biggest constraints in any robotic mission is power consumption of the robot. A robot gets its energy from onboard batteries. These batteries are charged by solar energy, using large solar arrays on the robot. In every activity the rover uses energy, therefore the sequence of activities for the rover is constraint by the amount of power available to complete the sequence. When the robot's batteries are low, it needs to return to a sun-exposed spot in order to recharge its batteries. Batteries are heavy artifacts that need to be brought up in space, and are therefore limited in size and power. This makes the whole robot power consumption issue a very important constraint in the design of the

---

[1] The name Victoria was chosen after the only ship of Ferdinand Magellan's voyage that circumnavigated the world. Ferdinand Magellan, (1480?-1521), Portuguese-born Spanish explorer and navigator, leader of the first expedition to circumnavigate, or sail completely around, the world.

robot, but also a very important constraint in the ability of the robot to perform certain activities during the mission, given a particular mission operation work system.

Victoria Mission Operations Work System

Figure.1 gives a pictorial representation of the known work system elements and their relative geographical location during the Victoria mission. The Science Team consists of a number of sub-teams, all co-located in Building 244 at NASA Ames Research Center, Moffett Field, California. The sub-teams are the Science Operations Team (SOT), the Instrument Synergy Team (IST), and the Data Analysis and Interpretation Team (DAIT). There are two other supporting teams outside the Science Team. These are the Data and Downlink Team (DDT) and the Vehicle and Spacecraft Operations Team (VSOT). All these teams work together to perform the mission. In doing so, their objective is to accomplish the scientific objectives of the mission.

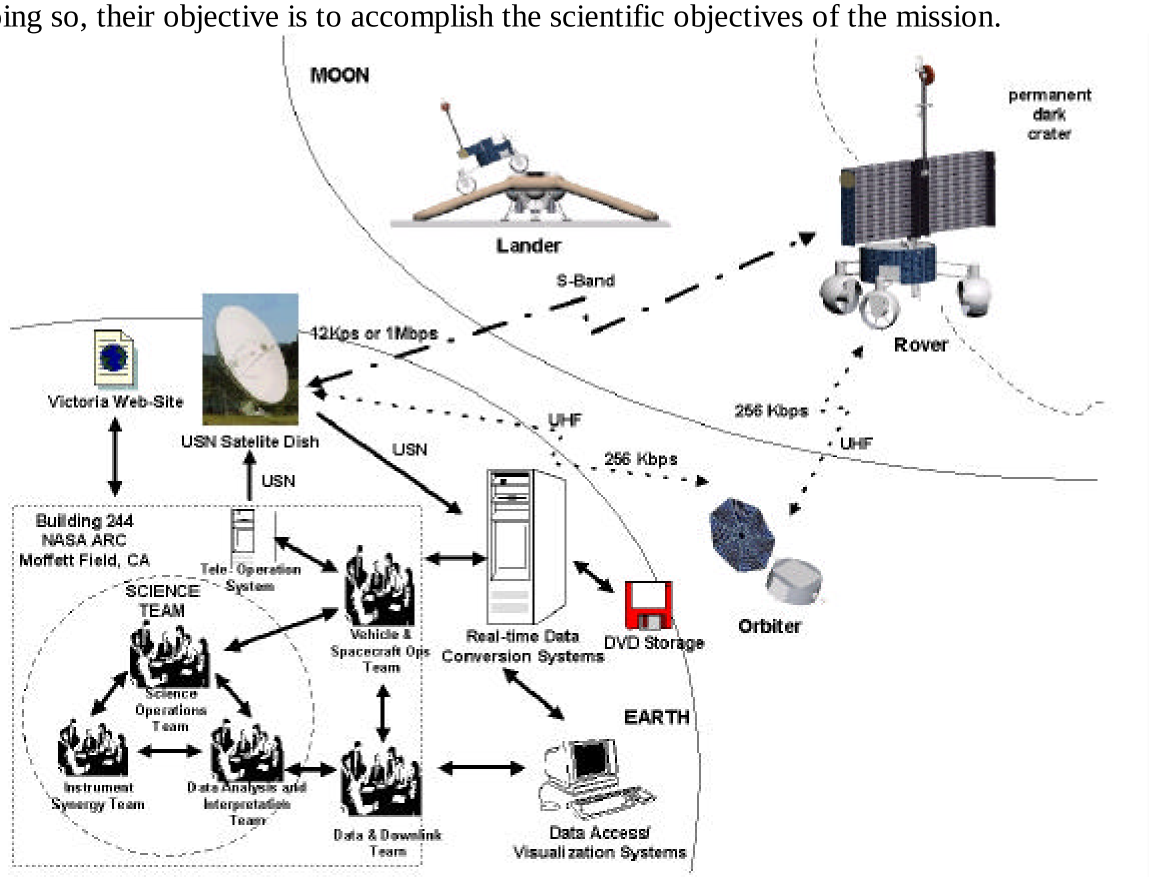

Figure.1. Victoria work system

Rover downlink data will come to NASA Ames via the Universal Space Network (USN) data connection and will be automatically converted in near real-time to accessible data formats that can be made available to the teams via data access and visualization applications. In the next sections we describe the design of this work system through the design of the agent model, the object model, their activity models and the geographical model

Downlink Activity

When the rover detects hydrogen in the ShadowArea1InCraterSN1 location the downlink process starts. What happens during the downlink process is shown in Figure 2. The VictoriaRover creates a data object with a) the current rover location information and b) the hydrogen data. This data object is then communicated to Earth, via the UsnDish1 object. The UsnDish1 object communicates this data to the DataConversionSystem, located at NASA Ames. As can be seen in Figure 2, the DataConversionSystem performs two conversion activities, one for the hydrogen data and one for the location data from the rover. When the VisualizationSystem receives the newly converted data, the system alerts the user, i.e. the DAIT team. This simulates the work practice that a member of the DAIT is monitoring the VisualizationSystem while in the activity "WatchForDownlink". When the DAIT agent detects that there is newly available neutron detector and location data, it retrieves the data from the VisualizationSystem object (i.e. the activities "RetrieveNeutronData", "InterpretNeutronData", and "FindRoverLocationData"). This simulates the DAIT team members looking at and interpreting the rover's neutron and location data, using the visualization system.

Then, the DAIT team communicates their findings to the SOT. The scenario states that the hydrogen data suggest that the rover has found hydrogen in the "ShadowArea1InCraterSn1" area. When the SOT hears these findings, it decides very quickly what the next command sequence for the rover is, and communicates this decision to the VSOT team (i.e. "CommunicateDoDrillActivity" activity).

The communication tells the VSOT team that they have to transmit the command sequence to the VictoriaRover. The command sequence tells the VictoriaRover to start the "SearchForWaterIceInPermanentDarkArea" activity.

Calculating Energy Consumption of Rover

The length of this downlink and second uplink process determines the length of the "Waiting" activity of the VictoriaRover, which simulates the time the rover is waiting for the Victoria science team to decide the next command sequence for the rover (not shown in this paper).

The model calculates the energy consumption for every rover activity during the simulation of the scenario, as is shown in Figure 3. The energy the rover uses during the "Waiting" activity is defined by the energy needed for *Thermal Protection during driving + Command and Data Handling during driving*. What this means is that even while the rover is standing still and "doing nothing," it consumes power for its thermal protection and its commanding and data handling for its subsystems, such as its processor board.

Figure 3 tells us that given the energy used in the scenario—drive 900m into the crater, and take one 1.0cc sample at 10cm depth—with the current work system design, the robot has used almost a third of its power:

$$EnergyRate(drilling\ in\ permanent\ dark\ crater) \sim 0.30$$

This variable represents the rover power consumption effectiveness of the work system design, and is a measure that can be used to compare different work system designs for a model scenario.

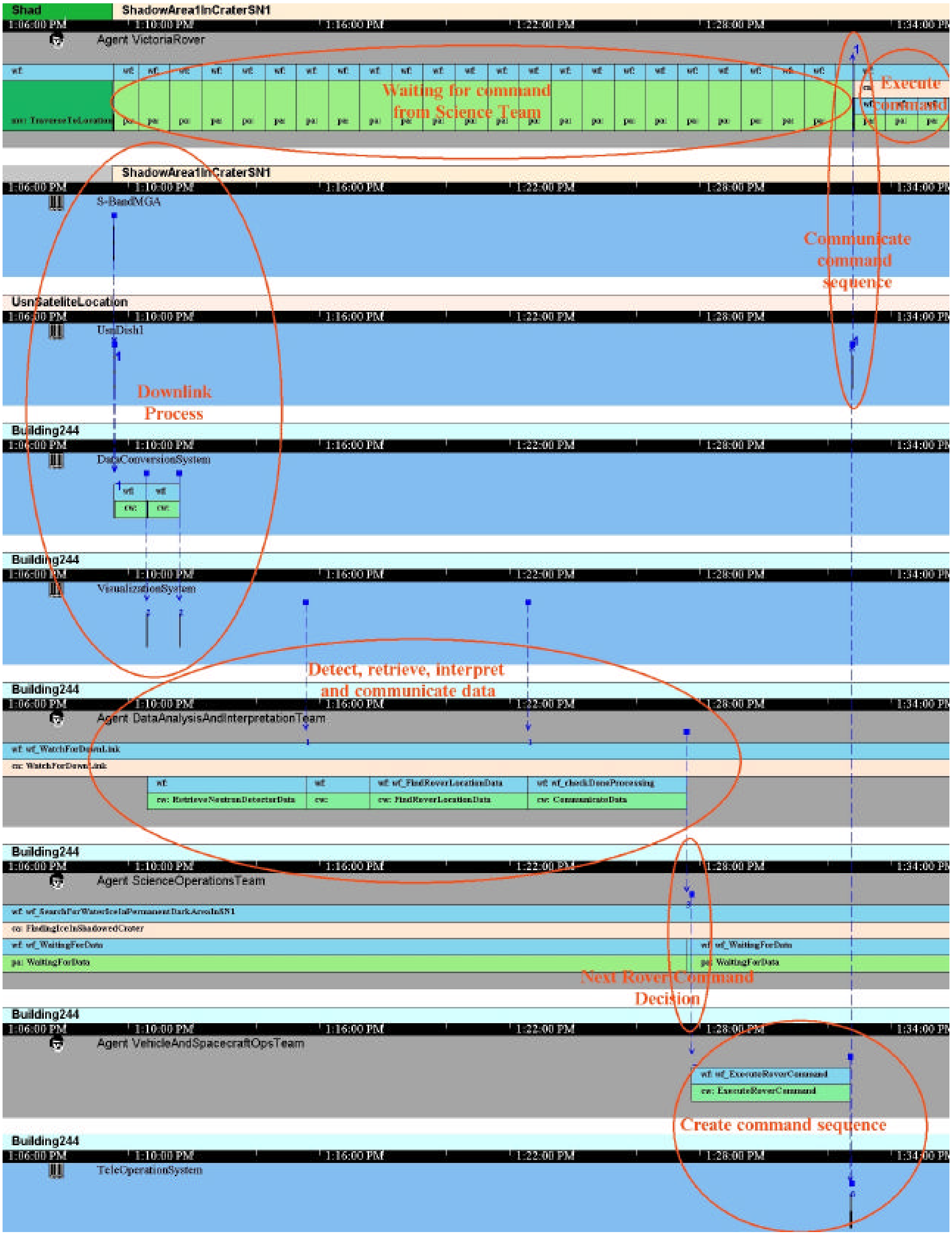

Figure 2. Simulation of downlink and second uplink command activities

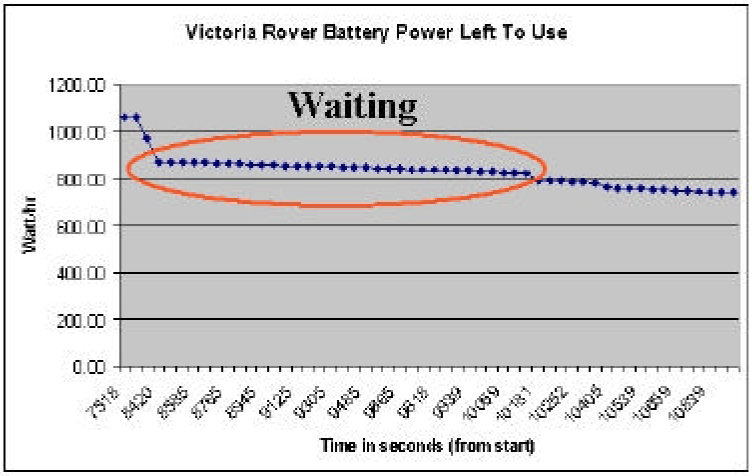

Figure 3. Rover battery power left based on activities

Conclusions

In this paper we described the use of the Brahms multiagent modeling and simulation environment in designing a work systems. We described how Brahms allows modeling at the work practice level, and showed how this methodology was used in a case study to design the mission operations work system for the proposed Victoria mission.

The benefit of using the Brahms approach in modeling a design of a new work system is that it allows for a representation of the behavior, communication and movement of the individual teams, as well as that of the rover and its instruments. This allowed showing the impact of the work process of the Earth-based teams on the energy consumption of the rover in performing a science mission, and thus shows the possible science result given the robot's capability and the work system design. Using the Victoria model will allow mission designers to compare different work system designs before critical mission decision have been implemented.

References

Cabrol, N. A., G. Chong-Diaz, C.R. Stoker, V.C. Gulick, R. Landheim, P. Lee and al., e. (In press) *Journal of Geophysical Research*, .

Clancey, W., J. (1997a) *Situated Cognition: On Human Knowledge and Computer Representations*, Cambridge University Press.

Clancey, W. J. (1997b) In *Human and Machine Expertise in Context*(Eds, Feltovich, P., Hoffman, R. and Ford, K.) The AAAI Press, Menlo Park, CA, pp. 247-291.

Clancey, W. J. (1998) In *Facilitating the Development and Use of Interactive Learning Environments*(Ed, Loftin, C. B. a. R. B.) Lawrence Erlbaum Associates, Hillsdale, NJ, pp. pp. 3-20.

Clancey, W. J., Sachs, P., Sierhuis, M. and van Hoof, R. (1998) *International Journal on Human-Computer Studies*, 49, 831-865.

Davenport, T. H. (1993) *Process Innovation: Re-engineering Work through Information Technology*, Harvard Business School Press, Boston, MA.

Hammer, M. and Champy, J. (1993) *Re-engineering the Corporation*, Harper Collins Publishers, Inc., New York, NY.

Sierhuis, M. (2000). Modeling and Simulation of Work Practices on the Moon, In *Computational Analysis of Social and Organizational Systems 2000* http://www.ices.cmu.edu/casos/papers_content.html, Carnegie Mellon University, Pittsburgh, PA.

Sierhuis, M. and Clancey, W. J. (1997). Knowledge, Practice, Activities, and People, In *Proceedings of AAAI Spring Symposium on Artificial Intelligence in Knowledge Management*(Ed, Gaines, B.) http://ksi.cpsc.ucalgary.ca/AIKM97/AIKM97Proc.html, Stanford University, CA., pp. 142-148.

Sierhuis, M., Clancey, W. J., Hoof, R. v. and Hoog, R. d. (2000b). Modeling and Simulating Human Activity, In *Autonomous Agents 2000 workshop on Intelligent Agents for Computer Supported Co-operative Work: Technology and Risks*(Ed, Petsch, M.) Barcelona. Spain.

Sierhuis, M., Clancey, W. J., Hoof, R. v. and Hoog, R. d. (2000a). Modeling and Simulating Human Activity, In *2000 AAAI Fall Symposium on Simulating Human Agents*, Vol. FS-00-03 (Ed, Freed, M.) AAAI Press, North Falmouth, MA, pp. 100-110.

Spudis, P. D. (1999). Robots vs. Humans: Who Should Explore Space?, In *Scientific American*, Vol. Vol. 10 , pp. 24-31.

Tyo, J. (1995). Simulation modeling tools, In *Information Week*, pp. 60-67.

Zeigler, B. P., H. Praehofer and Kim, T. G. (2000) *Theory of Modeling and Simulation,* Academic Press, San Diego, CA.