

Empirical Requirements Analysis for Mars Surface Operations Using the Flashline Mars Arctic Research Station

William J. Clancey, Pascal Lee, and Maarten Sierhuis

NASA/Ames Research Center¹
Computational Sciences Division, MS 269/3
Moffett Field, CA 94035
Contact: bclancey@mail.arc.nasa.gov

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Abstract

Living and working on Mars will require model-based computer systems for maintaining and controlling complex life support, communication, transportation, and power systems. This technology must work properly on the first three-year mission, augmenting human autonomy, without adding yet more complexity to be diagnosed and repaired. One design method is to work with scientists in analog (Mars-like) settings to understand how they prefer to work, what constraints will be imposed by the Mars environment, and how to ameliorate difficulties. We describe how we are using empirical requirements analysis to prototype model-based tools at a research station in the High Canadian Arctic.

During the past three field seasons, 1998-2000, NASA/Ames researchers have investigated the field practices of scientists and engineers at Haughton Crater on Devon Island in the Canadian Arctic, 500 miles north of the Arctic Circle, as participants in the NASA Haughton-Mars Project (HMP). The HMP is a Mars analog field research program based at SETI and Ames, with thrusts in *Science* (Comparative Planetary Geology, Astrobiology) and in *Exploration Research* (Information Technologies, Robotics, Human Exploration). As part of HMP Exploration Research, Ames human-centered computing (HCC) studies are determining how human explorers might live and work on planetary surfaces, in particular on Mars.

The HCC investigation of HMP field life and work practice spans social and cognitive anthropology, psychology, and computer science. The investigation involves systematic observation and description of work activities, locations, and learning in the field, constituting an ethnography of field science at Haughton. The focus is on human behaviors—what people do, where, when, with whom, and why. By locating behavior in time and place—complementing a functional or “task oriented” description of work—the research identifies patterns

constituting the choreography of interaction between people, their habitat, and their tools. These patterns are relevant to the design of a surface habitat and scheduling daily activities. The patterns are often not perceivable to members of the expedition; by representing them in the Brahms multiagent simulation system (Clancey et al. 1998; Sierhuis et al. 2000), we have a basis for improving collaborative design between engineers, mission support, and astronauts.

Many human behaviors are tacit and emergent in group interactions. For example, the work tent at Devon Island has often been used for storing tools and personal items. However, in referring to the place as a “work tent,” few people realized that half of the visits to the work tent occur in a minute or less and more than a third of the visits were under 30 seconds. Time lapse photography reveals such patterns. The summarized data provides a basis for a Brahms simulation, and the graphics for representing time-lapse patterns suggests how Brahms simulations might be usefully displayed.

As a second example, by systematically photographing a white board used for planning, we found that the lead geologist and biologist during HMP-1999 each visited 21 sites during an 18-day period, but the geologist visited 13 sites not visited by the biologist. The biologist tended to make many visits to the same site. This variation in exploration styles is important in planning traverses on Mars, where a team might be required to stay together.

To develop requirements for new kinds of tools for living and working on Mars, HCC research focuses on the existing representational tools (such as documents and measuring devices), learning and improvisation (such as use of the internet or informal assistance), and prototype computational systems brought to the field. This study of human exploration seeks first to understand field science on its own terms, as a form of *empirical requirements analysis*. The examples given above illustrate how empirical requirements analysis seeks to understand more about the work setting and human preferences than might

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¹ The authors have dual affiliations: Clancey: Institute for Human-Machine Cognition, University of West Florida, Pensacola, FL. Lee: SETI, Mountain View, CA. Sierhuis: RIACS, Moffett Field.

have immediate application to computer system design. Indeed, having such a broad understanding becomes a heuristic for ensuring that introduced technology does not have unintended consequences.

Application of model-based systems at Devon Island is focusing on requirements for habitat systems, computing infrastructure and data collection tools, and collaboration methods for mission operations support. The areas of most interest include:

- Communication protocols (mission support in Houston, collaborating PIs on Earth, the public)
- Telecommunication/ computer equipment (hab, rover, space suit, earth)
- Automation (life support, rovers, science, and exploration)
- Telescience, telemedicine, training

Two key problems were highlighted in the HMP-2000 expedition during a trial occupation of the FMARS. First, it will not be practical on Mars to repeatedly revisit sites merely for checking that scientific instruments are working and to download data. On Mars we will prefer to use telemetry for accessing remote instruments; data will be sent directly to the habitat and then back to Earth. One approach is to transmit data directly from a field-deployed instrument to a satellite, and then to an internet available both on the Mars surface and on an Earth. For example, the weather station already deployed at Devon Island could be connected to the FMARS and mission support in this way. With this infrastructure, it becomes possible to experiment with distributed human-machine learning, taking into account that both the crew and mission support will be learning about Mars phenomena, such as the weather, and that adaptive programs will be used to process data and monitor or control equipment.

A second problem is that we do not believe that it will be practical for several crew members to spend several hours a day composing and formatting reports to be “downloaded” to mission support. We need to find ways to automate the reporting process, such as by automated transcription of audio logs or by automated recording of crew movements.

One approach for augmenting human capabilities is to examine how computer tools have been adopted on a volunteer basis. The different ways in which computers are used in a modern field expedition were highlighted by a written survey completed by the participants in the month following the HMP-1999 field season. Important findings are summarized in Table 1. The greatest surprise is how many people downloaded and/or learned to use new software. Very likely new tools will become available during a three-year Mars mission. This highlights that training will be an ongoing activity, complicated by the time delay that will prevent conversations with instructors on Earth.

Aside from laptop computers, the most prevalent use of computing is the digital camera. The average number of digital photographs was 137, yet only two people used a photo database (on average 204 conventional photographs were taken per person). This information and related observations has suggested that we develop tools that combine databases, maps, GPS readings and digital cameras. Observations about internet usage are useful for determining whether a Mars crew should be allowed to interact directly with colleagues on the internet, or whether mission support should enforce the present-day protocol of having a mission support officer filter and reformat communications.

Table 1. Computer and digital device usage during HMP-99 expedition (N = 25)

Computer Usage	Percentage
Used a computer	92%
Browsed web	68%
Downloaded software	32%
Learned to use new software	52%
Sent e-mail	88%
Used e-mail daily	60%
Sent digital photographs	52%
Informed colleagues or sought advice	64%
Watched a full DVD movie	76%
Used a digital camera	64%
Used computer outside or in personal tent	16%

Together the time lapse analysis and surveys have highlighted the importance of systematic observations, by which events are counted. Patterns in use of space and tools are not obvious to members of the group, and are even missed by trained observers. Representing these patterns in the Brahms multiple-agent simulation system is becoming a key method for summarizing data and applying it to alternative work system designs.

In summary, HCC investigations during HMP expeditions have suggested several hypotheses that are shaping NASA’s operations planning and technology design for surface operations on Mars:

- Exploration is not just about covering the most area in the most time; continuously revisiting places is essential.
- Living on Mars might change scientific practice, physically constraining how the work is done and how analysis and publication are coordinated.

- An important use of computers will be for life support automation and mediating communication with Earth, not just for assisting scientists in direct field exploration.
- Protocols for Mars-Earth communications should be designed to help Mission Control learn about human activities on Mars and adjust its support role as surface practices develop.

These developing perspectives illustrate the value of an empirical requirements analysis process, by which computer scientists live and work with experts in an authentic, evocative setting. By characterizing behavior patterns (in use of facilities and tools, as well as teaming and scheduling), a baseline of preferred behaviors is established. Constraints on such behaviors on Mars can then be articulated, and protocols or tools developed that ameliorate difficulties. Prototypes are then brought to the work setting and experimentally used in controlled protocols. The quality of the work is examined and the process iterates. In this way, an analog setting provides a way of both articulating requirements, and trying out equipment, procedures, and training for an actual mission to Mars.

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