The View from Earth Versus the View from Mars[1]

Future missions to Mars pose problems for spacecraft designers that have never been encountered in any prior space mission. And, likewise, no prior human activity has ever asked so much from its crew. A typical Mars mission, for example, will carry its 4 to 6 human travelers on a half-year journey into deep space—a journey so far from the support and comfort of Earth that radio messages can take as much as 20 minutes each way. And upon arrival at Mars, the crew can look forward to a 1.5-year stay. The same orbital mechanics, which limits manned and cargo flights to brief yearly launch windows, makes unscheduled returns or unplanned re-supplies impossible. Everything that the crew might need, every vestige of home, every critical life support function, must be carried with them and must work reliably. And when the Earth becomes nothing more than a tiny blue star in the Martian night sky, all the comforts of human civilization are either completely lost or are replaced by spacecraft systems and supplies.

No other human endeavor has ever so completely broken the bonds between a small team of explorers and the help and support of Earth. Everything that the 6 or so crewmembers might need during the 2.5-year mission must be brought with them. Their spacecraft becomes their whole world—a complete ecosystem—and the Mars crew is utterly dependent on its near perfect functioning for their survival. We are not accustomed to thinking of the difficulty of maintaining homeostasis in our environment. Spaceship Earth is an enormous ecosystem with reservoirs so large that we can generally ignore the possibility of losing equilibrium, at least for the present. For Earth's ecosystem generally maintains its own equilibrium, in-spite of us. No one sets the concentration of oxygen in the air, the Earth's temperature or climate, the compositions of soil or the oceans, and so on. Nevertheless, they are maintained within very narrow limits. For this discussion, the "ecosystem" of human life on Earth should be greatly expanded beyond the conventional meaning of the term. All the products of human endeavor, the materials we use to construct our homes and cities, all our tools, our knowledge, everything that we use or come into contact with are part of our ecosystem. And all are easily available on Earth, magically appearing without much thought or effort on our part. But there are essentially no significant reservoirs for anything in a Mars Spacecraft, which must have everything the crew might need in a tiny mass, 1.2×10^{20} times less than the Earth's mass. The Mars Spacecraft and its inhabitants are totally dependent on the proper operation of thousands of control loops and associated equipment to maintain the delicate, un-buffered homeostasis of their remote existence. In a sense, the success of the mission hangs on a thread that depends on a deep partnership between man and machine to ensure their survival. And both man and machine must make their vital decisions and respond in real time, with little forgiveness for errors. The crew can't even depend on Earthly support for time critical information. In fact, the distances make real-time two-way conversations ludicrous. This means that the crew must be totally self sufficient to survive. Once the crew has pressed the red start button and the trans-Mars burn is complete, the crew is committed to go to Mars and not to return for at least a year. And once they are on the surface for about 30 days, they must wait a full 1.5 years on the surface of Mars before they can return. There really is no Earthly analog to this level of self-sufficiency.

To meet with all possible contingencies, the crew must be jacks-of-all-trades, they must know everything or be able to access arcane information in a hundred fields of Science, Medicine and Engineering. They must have instantaneous access to encyclopedic quantities of information and procedures. They must reason and respond to contingencies that go far beyond anything that they could have been trained for.

So we see that the crew will be faced with a flood of highly technical and often incomplete or uncertain data – data that must be organized and interpreted before anyone can understand or use it. Hence, they need intelligent systems that can separate the oceans of irrelevant or unimportant data from the truly interesting results. The answer is to build human-machine interfaces and automated systems that are smarter and possess the capability to encourage cooperation between users and machines. In essence the machine must act as a crew-multiplier in that it must allow each crewmember to do the work of many. The spacecraft systems themselves literally become "human-equivalent" helpers. And this too is, of course, a multiple task environment, which requires operators to process information from more than one source and to perform more than one task at a time. In the process an operator may be forced to choose certain tasks and, by necessity, neglect others. If an operator neglects a task and fails to return to it in time, the neglected task may become more important than the task attended to. The human-machine interface should aid the user in task management.

Skills and knowledge that were learned during training on Earth are not likely to survive intact for the full 2.5 years of a Mars mission unless there is continuous in-flight and on-surface training. In many cases, the training must be delivered just-in-time as it is needed, in lock-step with the activities of the automated systems. Such

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training systems may be based, in part, on virtual reality and virtual environments, augmented reality or similar technologies.

Ultimately, the heavy reliance of a Mars spacecraft on automation permits self-reliance. And future travel to Mars will force crews to be far more self-reliant than anyone has ever been. Vast amounts of information and intelligence must be built into spacecraft systems to allow them operate completely independent of Earth and, at each stage, human oversight will be required to ensure safety. In all prior space missions, crews have been supported by legions of technical personnel on Earth. To create spacecraft systems that enable autonomy, an understanding of human physical and cognitive capabilities is essential.

Human Centered Design revolves around the human users themselves, the work they do, how they do it, and their capabilities and needs. Automated systems designed from a technology centered perspective tend to place the human operator in either a monitoring role or completely out of the loop altogether. The goal is not to optimally balance operator workload with the automated systems but to replace humans completely. When there is a problem, the human user can override the automated system, but may be hesitant to do so—even when there is compelling evidence of a problem—because he or she would have to step into the system's shoes without a full understanding of the situation. The operator ends up wondering what the automated system is doing, why it is doing it, and what it will do next. There needs to be a way for the user and machine act as intimate partners where the allocation of tasks between humans and machines is handled dynamically. To create the required crew-multiplying effect, the interface between human and machine must be extremely fluid, constantly varying according to the changing needs of the crewmembers and the current situation. In this way the interface permits a very small number of humans to do what legions would otherwise be required to do. It makes ready use of human intelligence and skills when that is most appropriate, but falls back to human-tended, or even silent, automation when it is not.

A systems approach looks at all parts of a system under study, especially their interdependence and interactions. One way to view the systems nature of the Mars human-machine system is to liken it to the human nervous system. Just as the human nervous system provides spatial nets of sensory receptors, a Mars spacecraft has a network of sensors too. Spacecraft sensors potentially include strain gages and resistive, capacitive or inductive sensors; piezoelectrics, photovoltaics, and sensors of linear or angular-motion; accelerometers or vibrational sensors and fluid flowmeters; pressure, liquid level, temperature and humidity sensors; scintillation counters, Geiger-Mueller tubes and star trackers; pH sensors, and many others. The number and kinds of sensors in a Mars spacecraft will enormous.

Just as the most important output of the human nervous system is the control of bodily activity through contraction of skeletal or smooth muscle or the secretion of endocrine or exocrine glands, the major role of human-spacecraft system is ultimately system control through a variety of effectors such as electronic or mechanical switches or relays, motors, compressors, solenoids, valves, actuators, fans, thrusters, other control devices for thermal and life support systems, communications, power and navigation/guidance systems, or any of a large number of potential output devices.

Just as in the human nervous system, the processing of information in the spacecraft-human system can occur at varying levels—from monosynaptic reflexes in the spinal cord to conscious awareness in the highest areas of the cortex. In the spacecraft-human system, thermostatic control of temperature, for example, falls nearer to biological reflexes, while the human operator is most closely analogous to the highest integrative and associative areas of the cortex.

The spacecraft becomes an extension of the human being, allowing the crew to add spacecraft sensory systems to their own, mapping the new sensory information on already existing (and loaded) sensory systems. Machine intelligence compensates for man's inability to absorb an infinite quantity of inputs (man's sensory bandwidth) by processing the data at lower levels, filtering it to determine importance, and passing only those items into human consciousness that truly need human intervention. In the Mars human-machine system one can imagine that the number of bits of information are astronomically high, so considerable automation is involved in summarizing information on the current situation so the crew can rapidly understand it. At the same time it must provide decision support and expert advice.

Finally, in a Mars mission, the need to extend the intellectual and physical capabilities of the crew is critical to survival but we don't have the same need to reach this level of automation and human-centeredness on Earth.

Nevertheless the technologies that are developed for a future mission to Mars will have a profound effect on the way we do work. They may be expected to increase human capabilities and productivity many fold. But unless we do take on the challenges of a Mars mission and are willing to pay the high price, it seems unlikely that this will happen soon.