SOCIOLOGICAL CONSIDERATIONS FOR THE SUCCESS OF PLANETARY EXPLORATION MISSIONS

A WHITE PAPER SUBMITTED FOR CONSIDERATION TO THE
PLANETARY SCIENCE DECADAL SURVEY 2013-2022 COMMITTEE

> *"I have a belief that every mission is kind of like a living organism, it has a personality and it has a style, and that personality and style is sort of gained at the beginning of the mission and it never changes, even though the people migrate through it change, you change out the people and you still have the same mission personality…"*
>
> –*Scientist on Viking, Voyager, Cassini-Huygens, and MER* [29, p.40]

- Janet Vertesi, Information and Computer Sciences, University of California, Irvine
- Robert Pappalardo, Jet Propulsion Laboratory, California Institute of Technology
- Claudia Alexander, Jet Propulsion Laboratory, California Institute of Technology
- William J. Clancey, NASA Ames Research Center/Institute for Human and Machine Cognition
- Barbara Cohen, NASA Marshall Spaceflight Center
- Paul Dourish, Information and Computer Sciences, University of California, Irvine
- Jeffrey Johnson, US Geological Survey, Flagstaff, AZ
- Barbara Larsen, Jet Propulsion Laboratory, California Institute of Technology
- Kimberly Lichtenberg, Washington University Saint Louis
- Charlotte Linde, NASA Ames Research Center
- Scott Maxwell, Jet Propulsion Laboratory, California Institute of Technology
- Zara Mirmalek, University of California, San Diego
- Jeff Moore, NASA Ames Research Center

Address Author Correspondence to: Dr. Janet Vertesi
Donald Bren School of Informatics & Computer Sciences
University of California, Irvine
Irvine, CA 92697
jvertesi at uci dot edu

SOCIOLOGICAL CONSIDERATIONS FOR THE SUCCESS OF PLANETARY EXPLORATION MISSIONS

1. Summary

While planetary spacecraft are unmanned, the missions are manned, and must be understood in that way. This requires the addition of the social sciences to the science and engineering disciplines that develop them. In this White Paper, we argue that alongside scientific and technical considerations, the Planetary Science Decadal Survey should require that missions incorporate deeper consideration of the social science of spacecraft operations to maximize their missions' scientific, technical and fiscal success. After all, each mission's unique configuration of human interactions, relationships and roles lends it a different culture – a "style" or "personality"– that affects how the mission proceeds, how goals are met, and how science is done.

2. A Role for the Social Sciences

Thinking from a social science point of view offers many benefits to mission planners. For example, mission organization has traditionally arisen from a combination of funding structures, institutional relationships, and project heritage. When clashes erupt, participants may blame their colleagues' negative behaviors on politics or personalities, generating avoidance strategies that can inhibit effective collaboration. But in the social sciences, it is well-known that social structures exert strong influence on human behavior, as they present a culture, set of norms, roles, and requirements that shape local goals and which participants must adhere to in order to achieve them [7, 9]. If we make proactive organizational choices alongside our decisions about science goals, funding allocation, and technical design, we can optimize our science and operations, and reduce miscommunication and misunderstanding, resulting in more efficient and effective missions. Robotic space exploration also relies heavily upon technology and interactions with technology, from networked servers to planning software, from teleconferencing lines to the spacecraft itself. Recent developments in fields that have long considered the complex relationship between people and technology (i.e. Science and Technology Studies (STS), Human-Computer or -Robot Interaction (HCI/HRI), and Computer-Supported Co-operative Work (CSCW)) can offer both specific recommendations and a knowledgeable perspective from which to weigh social alongside technical and scientific concerns. As we move into a period of more advanced and more frequent robotic exploration missions, such insights must be taken into account in the process of mission planning to maximize mission success. Rather than suggesting a "social engineering" or a "one size fits all" approach, we present four interconnected themes – *mission organization*, *distributed operations*, *data management*, and *community development* – to demonstrate how sociological considerations may be fruitfully included and addressed during mission formulation and execution over the coming decade.

3. Mission Organization

Broadly speaking, NASA's planetary exploration program has historically relied on two scales of missions. First, Flagship-level "strategic" missions address large-scale, long-term science projects in the form of missions such as *Viking*, *Voyager*, or *Galileo*, which feature a large and commonly international personnel roster, multiple Principal Investigators, and "competing" science teams. Second, focused science missions under Scout, Discovery, and New Frontiers typically fund a single Principal Investigator and limited Co-Investigators. Such funding classes have resulted in new organizational and participatory structures with perhaps unforeseen effects on mission participants, their relationship to the project, and their science.

For example, the acclaimed *Mars Exploration Rover* (*MER*) mission features a single Principal Investigator (PI) and a suite of instruments whose data and operations are shared amongst a relatively small science and engineering team. This structure with its shared suite of resources has led to the multi-instrumental crafting of observations from the ground up: that is, the science questions that arise on the mission are addressed holistically via multiple sets of co-registered data, requiring intensive data sharing, joint interpretation, and multiple-authorship among the group's scientists [3,5,15,18,19,29,31]. Further, consistent with founding sociologist Emile Durkheim's description of the effects of the division of labor upon social cohesion [7],[1] *MER* members exhibit a high degree of allegiance to each other across instruments, roles, and institutional affiliations and commonly possess deep affective connections with their spacecraft [29]. This stands in contrast to typical strategic missions built on a multiple-PI model, where instrument teams compete internally for spacecraft resources. Thus an early decision about mission teaming structure may affect the team's cohesion and scientific process [30]. This is not to suggest that all missions must be designed this way, or that all PI-led missions operate this way. However, instead of preferring or associating one kind of teaming structure with one kind of mission class, if we put such organizational questions at the forefront we can better address each mission's scientific needs, designing a productive "style" within which science questions are addressed. Toward these ends, we make the following recommendations:

- **Ensure that the science questions and the organizational structure are mutually enhancing, and not at odds**. That is, if the science questions require multiple datasets and collaboration in order to address them, then the science teams must display the required flexibility and structures of collaboration to support such goals. Conversely, if the driving science questions require a more discipline- or instrument-centered approach, a multiple-PI model may be best suited to answering these questions. Careful consideration of the appropriate approaches and their balance can ensure that desired science and community participation goals are achieved.
- **Strategic missions should consider possible teaming structures that are more akin to that of a PI-led mission.** Not all flagships must 'look like' a traditional Flagship, organizationally speaking: decreasing the degree of differentiation among participants under a single PI or Project Scientist may encourage stronger interdisciplinary science during the crafting of observations. Scientists should not *a priori* conclude that the mission class or teaming structure affects its (or their) prestige. Rather, the teaming organization must fit the science, and vice versa.
- **The technical design of the spacecraft must support the organizational structure that permits the science**. For example, participants and instruments on the *Cassini* mission were selected in 1989 within the rubric of a Flagship craft that offered a high degree of instrumental independence through a scan platform and turntables, already used to great efficiency on missions like *Voyager*. But these were cut during a funding crisis in 1992, and the instruments were mounted instead on the body of the spacecraft. The resulting mismatch between the science teams' independence and expectations and the instruments' physical co-dependence produces what team members identify as heightened costs and time required for effective mission planning, affecting mission operations and support of science team objectives [22]. This presents a powerful "lesson learned": future decisions that place the spacecraft's technical and social structures into direct conflict must be avoided.

[1] Briefly, Durkheim's theory stipulates that tribal communities with more directly perceived relationships of exchange tend to feel primary obligations towards the wider group than towards their local, family or professional ties, while members of distributed industrialized societies featuring greater distance between production and exchange feel more responsibility towards their local social group than towards society as a whole.

- Philosophers of science have proposed that **the incorporation of sometimes radically different points of view provides an improved route to objective results** [10,15]. In our case, the relevant point of view may be provided by different science instruments. For example, much of the recent detection and analysis of phyllosilicates on Mars is made possible by the co-registration of datasets from a plurality of ground- and orbit-based detectors. Mission designers interested in aligning multiple perspectives to achieve synergistic results must consider how co-registration is both a technical and a social decision. That is, (1) the detectors must themselves be properly aligned on the spacecraft and their datastreams must be in combinable formats or easily accomplished through shared software packages, and (2) the teams that plan and share observations must also be able to do so freely. Should missions choose to conduct interdisciplinary investigations in the guise of Interdisciplinary Scientists (IDSs) who can draw upon multiple instrumental resources, rather than negotiating to use narrowly defined data types, these scientists must be guaranteed access to any relevant datasets from the outset.
- **Decisions about organizational requirements must be articulated in the Announcement of Opportunity** so that proposing teams can configure themselves to best address the science questions within the funding level allotted. New requirements, especially unfunded mandates, must be minimized and their sociological implications considered and thoroughly addressed.

4. Distributed Operations

Over the past two decades, NASA has increasingly turned to "remote" or "distributed" operations systems to control the costs and human resources associated with mission management. The conglomeration of scientists, engineers, networks, and robots form "collaboratories" and "cyberinfrastructures," consistent with other collaborative endeavors in science [27]. But scientific cooperation occurs not only through a common understanding of ways to solve problems, but a common orientation towards how the mission is organized and how people normally interact [23]. Thus a major challenge in distributed operations is the maintenance of this shared culture across the different groups who make up the larger team [8,17]. Further, both *time* and *distance* impose significant obstacles: not only because colleagues and robots may be working in different planetary time zones [2,18,19], but also because informal aspects of group work are more easily achieved in co-located groups [21,25]. Software and hardware to support protected networks, data sharing, video- and tele-conferencing exhibit a mixture of commercially available resources and those written "from scratch," and technical glitches are common. But remote operations can also present benefits as it supports participants' family lives, careers and students, and provides different institutions with authority over their own production. Designing the process with eyes wide open requires sensitivity to "the human infrastructure of cyberinfrastructure" [14] by addressing the following issues:

- NASA and its participating institutions must **invest in networked video and teleconference technologies and associated hardware and software to facilitate remote operations at all levels**. Such may leverage existing commercial systems (i.e. email, shared calendars) but cannot be done on an *ad hoc* basis. Funding must be provided to ensure such systems are functioning and in place at the outset of a mission, to be used as a background resource across missions.
- Existing missions have crafted some extremely successful tools for mission planning (i.e. Maestro/SAP on *MER*, PSI on *Phoenix*, and CIMS on *Cassini*), but these remain local resources. Such in-house development teams should be supported to **produce base or open source versions of these programs that can be shared across mission platforms, and across institutions, with customization available for individual mission and institutional needs.** This can reduce the need to reinvent the wheel with each mission while maintaining flexibility.

- In the distributed phase of a mission, it is currently common for team members to work together for over a year without meeting each other face to face; however, this has repercussions for a team's sense of trust and ability to work together. Initial, formative phases of operations must therefore be leveraged to build the requisite shared organizational culture, patterns of interaction and degree of trust in a face-to-face environment to sustain the team [25]. In addition, **funding must be provided to support face-to-face meetings and associated social activities at least twice a year among the entirety of the science and engineering teams** to maintain healthy communication and collaboration. Scientists see each other regularly at external conferences, and a typical engineering team is co-located at an operational institution, but encouraging strong, ongoing working relationships across the mission is essential to project success.
- As a numerical representation of the time of day on Mars, Mars time (as employed on *MER*) supports the coordination of work between solar-powered robotic space vehicles and human workgroups across planetary worksites. But the social processes and technologies that humans use to establish and maintain a sense of time between time zones on earth – such as routines or watches – cannot be directly applied to establish and maintain a sense of time between interplanetary standards of clock time and solar time [18]. To respond to such pressures with adequate technologies and workflow scheduling, we must consider how time is itself both a kind of technology and a cultural construction that emerges from the physical relationship between human bodies and our environment [1,32]. When conducting mission operations according to solar time on another planet, **work support technologies should address the kinesthetic experiences of solar time that involve sensory perception and situational cues: such as the appearance of light, its gradations, and/or its absence, as well as surrounding environmental responses** [18].

5. Data Repositories and Availability

Before the internet was widespread, spacecraft data were controlled, printed, and disseminated as physical copies from a central point. However, significant changes in the role and culture of the digital era – from file sharing to Web 2.0 and the Open Source movement – have crafted new and wider communities of "users," alongside a belief that data should be both free and instantly available as soon as it hits the ground. This belief is often inconsistent with that held by PIs who negotiate proprietary periods in which to accomplish their science, causing tension on existing missions whose internal rules were negotiated before this cultural shift took place. Further, scientists external to the mission who eagerly await the delivery of data to the community via the Planetary Data System face a variety of disappointments when attempting to use the data, not necessarily due to poor attention to data delivery on the part of PIs. Issues that plague data management cannot be dealt with as "an afterthought" following the commotion of primary observations: instead, mission planners must incorporate their proposed values and strategies of data management into the fabric of their mission from the outset. To demonstrate their commitment to the transfer of human and instrumental knowledge, future missions must consider the following recommendations:

- **Data distribution policies must reflect operating principles**. Alongside its scientific value, data acquires social value as it is crafted in spacecraft operations. When instrument teams can only successfully acquire data through competition over spacecraft resources, and when this data is kept proprietary among instrument teams on the same mission, then this data is not "free" and cannot be considered so by the funding agency. Because significant personal resources went into its creation, proprietary measures must be upheld in order to respect the difficulties PIs and others went through in order to produce the data and conduct the investigation they were contracted to produce. Conversely, when data is crafted through collaboration and is shared among members of a spacecraft team, the data is imbued with a different value – that of an open and a shared resource – permitting easier sharing policies with outside researchers. Importantly, some PIs believe that scientific discoveries can only be produced via thorough checking by the group who work daily with the instrument and its results, while others adhere to a more Open Source model of collective knowledge production. Projects are advised to discuss in advance the kinds of data distribution they would like to see among their public audience, their peers, and their fellow PI's *that they believe will result in the best possible science*, and ensure that this vision for the data's distribution is consistent with the value it acquires in production.

- **Invest in the Planetary Data System (PDS)**. The Earth Science community uses the robust National Geophysical Data Center (NGDC), with a staff of scientists who interact with archive users and also conduct research using the data, thus assuring that data products are received/developed that actually work for a large community of users. The PDS, by contrast, accepts data on largely a volunteer basis, resulting in inconsistencies and user challenges. Suggested PDS improvements include but are not limited to: ISIS software development and support to allow a standardized approach to the calibration and use of not only imaging, but ultraviolet and infrared spectrometer results; broad-based search tools that leverage new search and display technologies (i.e. Google or Google Earth) to better locate and contextualize data relative to search terms; robust visualization tools; spacecraft orientation, pointing, and timeline tools; and reduction of the stove-pipe approach to how and what sort of data is stored.
- **Data management for mission operations and data management for archival purposes are two different systems, with different requirements and user bases.** Incompatibility between 'working' and 'archive' systems is currently addressed unevenly and on an *ad hoc* basis. More constructive relationships between PDS managers and PIs might ensue if such considerations are built into the system from the ground up or facilitated at the point of transfer, and if both are familiarized with the growing literature on collaboratories [8,11,12,21] that address this problem. Fully addressing data archiving issues must be done at the NASA level, or even at the level of national policy: they cannot be left to mission decisions, and particularly to mission budgets.
- Instrument management comprises what sociologist Michael Polanyi describes as "tacit knowledge": knowledge which, like riding a bicycle or brushing teeth, is impossible to describe in words but must be transferred through demonstration and person-to-person learning [24]. Seminal work in Science and Technology Studies on experimental replication has also shown that working with another's instrument or another scientist's data is almost impossible without access to one of the initial experimenters, complete with their familiarity with instrumental quirks, and kinesthetic memory of where the spacecraft took its data [6]. To be serious about making data available to those not on the instrument team, **investment must be made in facilitating such human interactions and transfer of knowledge**. Suggestions include data workshops, short-term "in residence" programs for team members to visit other locations or institutions where work with the data is taking place (or *vice versa*), funded workshops at field conferences, and the use of internet video to record and present examples of working with data. [2]

[2] Much on the subject of knowledge transfer can be learned from NASA's successful collaborations in the Astrobiology Institute and in the developing Lunar Science Institute. The CRISM data workshop at LPSC 2009 is also a good example of a face-to-face approach to building non-team-members' familiarity with instrumental data: http://geo.pds.nasa.gov/workshops/CRISM_Workshop_Mar09.htm

6. Development of Scientific Human Resources

In addition to the scientific discoveries they offer, missions provide extraordinary opportunities to train the next generation of planetary scientists and to expand collaborative networks and partnerships. Unlike many other fields, planetary science graduate students and postdoctoral scholars can become key contributors on a mission team, and those who begin on missions as students commonly end up as the successful proposers on subsequent missions. In addition, as individual agencies' budgets tighten, international partnerships are increasingly important for sharing the risks, workload, costs, and rewards of interplanetary missions, but they come with particular challenges that must be addressed in order to be successful. In particular:

- **Build succession planning strategies into all proposals for missions over 5 years in duration**. Long-term missions to the outer planets can last up to thirty years, but few mechanisms other than post-mortem or *ad hoc* inheritance are invoked to respond to generational change, or to acknowledge the role of former graduate students as they become, effectively, full-fledged team members. To respect the generational aspect of these planetary endeavors, mobility through team hierarchies must be explicitly considered in a manner consistent with mission design and goals .
- **Renew calls for Participating and/or Interdisciplinary Scientists at appropriate intervals**. Cycling new blood through a mission not only allows for new ideas and widens participation—it also provides opportunities for those who started on a mission early in their careers to join as team members as their careers progress.
- **Make available a variety of roles to train younger scientists and engineers and/or facilitate their options for productive exchange**. For example, the *MER* team has several "engineering lite" roles that scientists can occupy, monitoring or producing code for the cameras or other sensors on board. Such "legitimate peripheral participation" [13] offers great benefits as, on the one hand, junior members learn about spacecraft management in preparation for their own potential careers as PIs, and on the other, they stay "on the line" with the operations team all day, facilitating exchange, heightened understanding, and bridge-building between scientists and engineers. Not all spacecraft teams will or should support such roles, but thinking constructively about how to develop these or related skills can greatly improve chances of mission success.
- **Make Data Analysis grants available to postdoctoral and doctoral students on a mission to "go on exchange" to other institutions and/or instrument teams** to learn how things are done in other places, build familiarity with a variety of datasets, and forge relationships that will lead to broader collaborations and the next generation of science questions and associated missions.
- **Provide basic intercultural communication training for PIs and Co-Is working on international missions**. Culture clashes impede collaboration and require a steep learning curve, with uneven results. Many organizations outside space science have benefited from professional workshops on intercultural communication, which teach participants about their home cultures' assumptions and how those differ from those in other countries, in order to build more effective, productive, and communicative teams [20,25]. Adoption of some of these techniques can assist in leveraging the full scale of benefits offered by international partnerships.
- **Encourage effective changes to the International Traffic in Armaments Regulation.** Continued exploration of the solar system will require international cooperation, goodwill, and resources. But ITAR enforces significant barriers towards international participation, understanding, and the conduct of science. Further, as ITAR discourages open and full cooperation with American partners, NASA's international competitors develop their own partnerships and invest further in spacecraft systems R&D, thus producing the opposite effect to the legislation's aims.

- **Support availability for ongoing human-centered research and recommendations** with active mission teams. This may include not only participation from Human-Centered Computing researchers at facilities like NASA Ames, but also funding for continuing studies to support the extended mission phase, or fellowships for researcher training on current missions. Missions may even wish to experiment with the inclusion of a position for a trained social scientist on their team who can offer ongoing perspectives on and recommendations with regards to social, psychological, and human-centered computing factors throughout mission operations [15,31].

7. Conclusion

The intent of this White Paper is not to imply one-size-fits-all solutions; rather, it is to draw the planetary science community's attention to the importance of incorporating thoughtful decisions about these human factors into the very design of their spacecraft and mission teams. Such attention to sociological insights and research at the outset and throughout mission operations can offer great benefits towards achieving mission goals, whether technical, scientific, or cost-related. After all, despite our spacecraft, it is people – not robots – who are exploring these new worlds [4].

Works Cited

1. Adam, B. (1995). *Timewatch*. Cambridge, MA: Polity Press.
2. Bass, D. Wales, R. Shalin, V. (2005) "Choosing Mars-Time: Analysis of the Mars Exploration Rover Experience," *Proc. IEEE Aerospace,* March 5-12, Big Sky Montana.
3. Cheng, L., Spanovich, N., Vaughan, A., and Lange, R. (2008) Opposite ends of the spectrum: Cassini and Mars Exploration Rover Science Operations. *AAIA* 2008-3544.
4. Clancey, W. J. (2006) "Clear Speaking about Machines: People Are Exploring Mars, not Robots," *Association for the Advancement of Artificial Intelligence Workshop: The Human Implications of Human-Robotic Interaction*, Boston, MA.
5. Clancey, W. J. (in preparation). *Voyages of Scientific Discovery with the Mars Exploration Rovers*. NASA History of the Scientific Exploration of Earth and Space Grant HSEES06-0005.
6. Collins, H. M. (1985) *Changing Order: Replication and Induction in Scientific Practice*. London: Sage Publications.
7. Durkheim, E. (1896) *The Division of Labor in Society*. New York: Macmillan, 1933.
8. Finholt, T. and Olson, G. (1997) "From Laboratories to Collaboratories: A New Organizational Form for Scientific Collaboration," *Psychological Science*, 8(1), 28-36.
9. Haney, C., Banks, W. C., & Zimbardo, P. G. (1973) Interpersonal Dynamics in a Simulated Prison. *International Journal of Criminology and Penology*, 1, 69–97.
10. Haraway, D. (1991) *Simians, Cyborgs, and Women*. New York: Routeledge.
11. Hinds, P. and Kiesler, S., Eds. (2002) *Distributed Work.* Cambridge, MA: MIT Press.
12. Kellogg, K., Orlikowski, W., and Yates, J. (2006) "Life in the Trading Zone: Structuring Coordination Across Boundaries in Postbureaucratic Organizations," *Organization Science*, 17(1), 1-22.
13. Lave, J. & Wenger, E. (1991) *Situated learning: Legitimate peripheral participation.* New York: Cambridge.
14. Lee, C., Dourish, P., and Mark, G. (2006) "The Human Infrastructure of Cyberinfrastructure," Proc. *CSCW* 2006 (Banff, Alberta), NY: ACM, 483-49.
15. Linde, C. (2006) "Learning From the Mars Rover Mission: Scientific Discovery, Learning and Memory," *Journal of Knowledge Management*, 10 (2), 90 – 102.
16. Longino, H. E. (1990) Values and Objectivity. In *Science as Social Knowledge: Values and Objectivity in Scientific Inquiry* (pp. 62-82). Princeton: Princeton University Press.
17. Mark, G. (2002) "Conventions and commitments in distributed groups," *Computer-Supported Cooperative Work: The Journal of Collaborative Computing*, 11(3–4), 349–387.
18. Mirmalek, Zara (2008) *Solar Discrepancies: Mars Exploration and the Curious Problem of Interplanetary Time*. Ph.D. Dissertation, UCSD Communication & Science Studies.
19. Mishkin, A. H., Limonadi, D., Laubach, S. L., Bass, D. S. (2005) "Working the Martian Night Shift: The MER Tactical Operations Process," *Robotics and Automation Society Magazine*, Special Issue on MER.
20. Olson, G. and Lau, A. (2007) "Intra- and Intercultural Collaboration in Science and Engineering," Proc. *IWIC 2007* (Kyoto, Japan), NY: Springer, 249-259.
21. Olson, G. and Olson, J. (2000) "Distance Matters," *Human-Computer Interaction*, 15(2-3), 139- 178.
22. Paczkowski, B., Larson, B. and Ray, T. (2008) Managing Complexity to Maximize Science Return: Science Planning Lessons Learned from Cassini. *IEEEAC* paper #1590.
23. Pentland, B. and Feldman, M. (2005) "Organizational Routines as a Unit of Analysis," I*ndustrial and Corporate Change*, 14(5), 793-815.
24. Polanyi, M. (1966). *The Tacit Dimension*. Gloucester: Smith.
25. Samovar, L. and Porter, A. (2008) *Intercultural Communication: A Reader*.
26. Teasley, S., Covi, L., Krishnan, M., and Olson, J. (2000) "How Does Radical Colocation Help a Team Succeed?" Proc. *CSCW* 2000 (Philadelphia, PA), 339-346. New York: ACM.
27. Traweek, S. (1988) *Beamtimes and Lifetimes: the World of High Energy Physics*. Harvard University Press.
28. Trimble, J. Wales, R. Gossweiller, R. (2004). NASA's MERBoard: An Interactive Collaborative Workspace Platform. In O'Hara, Perry, Churchill and Russell (eds), *Public and Situated Displays*. Dordrecht: Kluwer.
29. Vertesi, J. (2009) *Seeing Like a Rover: Images in Interaction on the Mars Exploration Rover Mission*. Ph.D. Dissertation, Cornell University Science & Technology Studies.
30. Vertesi, J. and Dourish, P. (2008) "The Social Life of Spacecraft." LUCI Technical Reports, LUCI-2008-09.
31. Wales, R. Shalin, V, Bass, D. (2005) Requesting Distant Robotic Action: An Ontology for Naming and Action Identification for Planning on the Mars Exploration Rover Mission. *Journal of the Association for Information Systems*, 8 (2): 6.
32. Zerubavel, E. (1979). *Patterns of Time*. Chicago: University of Chicago Press.