

Choosing Mars Time: Analysis of the Mars Exploration Rover Experience

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Abstract—This paper focuses on the Mars Exploration Rover (MER) mission’s management decision to work on Mars Time and the implications of that decision on the tactical surface operations process as personnel planned activities and created a new command load for work on each Martian sol. The paper also looks at tools that supported the complexities of Mars Time operations, and makes some comparisons between Earth and Mars Time scheduling.¹²

or “sol”, is approximately thirty-nine minutes longer than an Earth day. Mission planners chose to link the Earth-based operations work to the Martian day-night cycle to optimize the work of the solar powered rovers and maximize precious rover time in the Martian environment. Each day surface operations personnel produced a planned set of activities and associated commands that were sent to the rovers so that they could do their work of data collection beginning on the following morning at rover wake-up.

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1. INTRODUCTION: MISSION OVERVIEW

NASA’s Mars Exploration Rover (MER) Project successfully landed two spacecraft carrying identical rovers on opposite sides of the surface of Mars in January 2004 and conducted two nominal surface missions staffed on “Mars Time” for 90 Martian days each [1]. A Martian day,

Figure 1 (below) shows the Mars Exploration Rover mission timeline that begins with the receipt of data from the spacecraft and completes with a set of commands approved and radiated to the spacecraft for execution the following morning. The time system portrayed in this figure is Mars Local Solar time (MLST), approximately thirty-nine minutes longer than an Earth day. In the chart, action steps are represented by royal blue bars, and meetings and handovers are represented by green bars. The light blue bar indicates the time when the rovers execute commands on the Martian surface. In the Mars Time scenario, the Earth-based team works while the rovers sleep. Grey represents the window in which data will be returned from Mars. While the grey bar appears long, it represents a window in which a 30-minute transfer of data will occur. The time that data is returned varies within the window, and is predictable several days in advance.

Figure 1 allows for the worst-case scenario with regard to late data arrival leaving enough time to ensure that the Earth-based team can produce the necessary results in the shortest time possible. Data can return to Earth either directly from the rovers on the planet surface or from spacecraft currently orbiting Mars. The four vertical bars at the top represent all options for returning relayed data through orbiting spacecraft (Mars Global Surveyor, or MGS, and Odyssey, or ODY); the light blue bar represents data returned directly from the planet’s surface. Four satellite relay possibilities are described but not all are routinely used each sol. The 10-hour “downlink shift” staff analyze the received data and make recommendations for rover activity execution, while the two 10-hour “uplink shifts” turn the recommendations into commands the spacecraft can understand. The process, as planned,

¹ 0-7803-8870-4/05/\$20.00©2005IEEE

² IEEEAC paper #1162, Version 7, Updated December 10, 2004

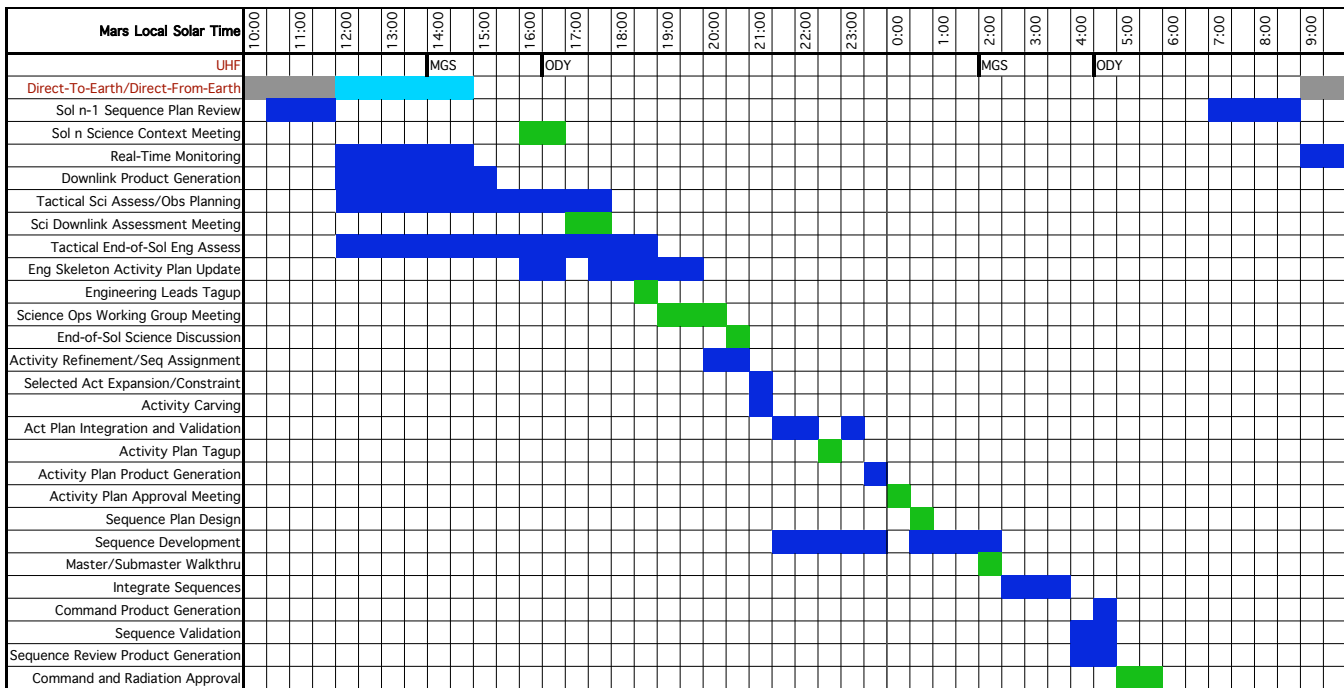


Figure 1. Mission Timeline detailing steps between receiving data from the spacecraft and sending a complete set of instructions to the rover. (Courtesy, Science Team)

originally took 19 hours to complete; by the beginning of extended mission operations, with improvements in automation, increased staff training and expertise development, the process took an average of 8 hours.

What is Mars Time?

Because the Martian day is approximately thirty-nine minutes longer than an Earth day, participants who worked on Mars Time reported to work later each Earth day in order to remain synchronized with the solar powered work of the rovers were doing. For example, a participant might report to work at 12 noon on one day, 12:39 the next day, 1:18 the next day and so on. In addition to the daily, or “soly,” tactical process of planning and commanding on Mars, other mission work, known as the strategic process, focused on planning over longer periods of time and was responsible for long term mission activities and resource allocations. The strategic processes included coordination of the work of the two missions, coordination and allocation of Deep Space Network and orbital communication coverage within and across missions, determination of overall rover resource situations and public outreach activities. Tactical work on MER was done on Mars Time, while strategic work was done on Earth time.

This paper focuses on the MER mission decision to work on Mars Time, the implications of that decision on the tactical surface Mars Time work, the support needed from related tools and the impact that Mars Time had on the work of personnel as they planned activities and created a new command load for each Martian sol.

2. MARS TIME TRADE STUDY

The case for Mars Time centers on the following argument: a landed spacecraft operated on solar power is a dying asset. The mission duration is limited by the amount of sunlight the solar panels receive. Further, the spacecraft may fail to respond on any given day, and therefore it is critical to maximize the use of that asset. Arguably, Mars Time optimizes that usage. However, maintaining Mars Time in an Earth time world poses problems including some typical of shiftwork [2] and some that were somewhat more surprising.

Early in the development of the mission, in response to a design review, MER management launched a study to help determine whether to use Mars Time staffing. They were looking for an optimal operations schedule for coordinating the work of two hundred and fifty mission personnel on Earth who would be operating dual rovers on Mars. The main question was whether operations processes should be conducted on an Earth time schedule or a Mars Time schedule. The MER staffing options had to consider the following criteria:

- Allow for personnel to be fully trained for surface operations before landing day,
- Acknowledge that personnel would take longer to do their work early in the mission while they developed expertise,
- Provide the capability to command every Martin sol,

- Provide margin for dealing with contingencies within the nominal timeline,
- Minimize the impact of scheduling on personal lives,
- Be sustainable over the life of the nominal mission.
- Ensure communication of key information across shift boundaries,
- Possess resiliency in the face of anomalies,
- Support operations of two rover missions simultaneously,
- Maximize the use of shared facilities, such as meeting rooms and the engineering surface support area,
- Maximize the potential for science return,
- Minimize the risk to the spacecraft.

Considered Staffing Options

The mission considered a variety of staffing options. We present here an analysis of the two extreme cases.

Evaluation Metrics

Five functional areas for metrics were identified, and a relative weighting for each area was applied.

• Number of Personnel	150
• Impact on Facilities	100
• Impact on Personnel Morale	100
• Complexity of Process	150
• Achieve full Mission Return	400
• Impact of other Human Factors	100

A perfect score for a particular staffing option would total 1000 points.

Baseline Mars Time—The baseline Mars Time option focuses staffing resources both in time and with regard to tasking. On an assigned workday, each person comes to work at approximately the same Mars local time and does whatever s/he does best. Key characteristics of this option include: at least one opportunity to uplink commands to the spacecraft each day, 4 hours of margin in the schedule, personnel work the same functional position each duty cycle, shift start moves 39 minutes later each day while the operations tasks stay synchronized with the Mars clock, as do individual work schedules. Shift overlap from downlink to first uplink shift (Uplink1) is approximately one hour, overlap from Uplink1 to Uplink2 is 1 hour, whereas Uplink2 to Downlink shift would not overlap. (Note that this absence of overlap was ultimately deemed unacceptable to MER management, and key operations staff was placed so that there was always face-to-face handovers of information between all shifts.) Shift handovers always occur at the same point in the process. This option did not necessitate “split shifts” where an operator finished the second part of his or her shift the following morning. Analysis indicated that this schedule would include one-third night shifts over the duration of the 90-day mission. Because the operations area would be continuously staffed in this option, the ability to respond to off-nominal

situations and respond to ad-hoc science team requests was maximized.

Earth time – Prime Shift

This option employs a single long shift each day (up to 8 hours), so that the rover lacks a ground team “babysitter” for as many as 16 hours per day. People keep the same time schedules each day and stop at the end of the shift, independent of Mars Time. Only eight hours between the Mars afternoon downlink and the uplink the following Mars morning can be populated with rover activities, in general, and sometimes as little as 3 hours. Shifts are fixed times, and work flows over to the next day, whatever the work’s status. Cross training is essential for this option, as personnel duties must support the schedule of the rover on Mars Time, and staff must be capable of some productive activity during any phase of mission operations. The ability to command every sol is precluded because a shift may not be able to prepare an uplink plan within the available Earth-based work window. This option is based on the concept that the process will allow commanding as often as possible but that commanding will be limited to the ability to complete work within the Earth time schedule.

Other Components of the Trade Study

MER mission designers also made an effort to gather data on the effectiveness of operating on Mars Time from members of the 1997 Mars Pathfinder mission. Personnel worked on Mars Time for roughly 87 days during that mission and it was the only reference mission for such staffing activity. Although there was some variation in recollection among participants, overall most Pathfinder operations personnel, when questioned informally, agreed that the 1997 Mars Time schedule had advantages and disadvantages and the trade-off decisions were difficult. NASA Ames Human Factors personnel made two studies for the mission; one was a recommendation for work based on a review of the physiological factors that contribute to alertness and performance among shift workers and another was a questionnaire filled out by Mars Pathfinder personnel who had gone through the Mars Time staffing experience in 1997 [3, 4].

Trade Study Conclusions and Recommendations

Mars Time staffing plans consistently scored better than Earth time for:

- Ability to command every sol
- Optimal time utilization, conservation of margin
- Response to off-nominal situations
- Maximized potential mission return
- Little or no cross training required

However, Mars Time staffing plans scored lower in sustainability, resulting in the following conclusions:

- Mars Time staffing requires more crews to sustain extended duration operations
- Straight Mars Time can be sustained for short duration (<30 sols) [5].

With respect to short-term mission concerns, Mars Time was determined to be the most efficient staffing solution: the operations schedule was fixed to Mars Time, which created the most margin in the day by maximizing the available time. Margin was recognized as a critical component, necessary early in the mission when the team was still learning some of the quirks of the vehicles, and tools and processes are still being fine-tuned. Therefore, the decision was made to operate on Mars Time at least for the short term.

It was recognized that Mars Time would not be sustainable indefinitely due to the need for people to interact with families and duties outside of the mission environment; it is not possible to isolate people indefinitely from their broader responsibilities and personal commitments. "In the beginning, the adrenaline is going and everyone is pretty focused. External stresses can be pushed off. But you can't carry that forever." (Mars Pathfinder mission system team member, personal communication) Indeed, it was recognized that working on Mars Time is a matter of scale and longevity. Therefore, in the long term, the strain on the team would be evaluated, and the switch to an Earth time schedule would be considered.

The Ames Human Factors reports recommended that the MER project develop strategies to maximize performance and minimize risk to mission success and personnel health. In particular, they recommended that staff members work no more than 4 shifts on Mars Time in a row, followed by several days off to allow enough time to recover from Mars Time operational shifts [3].

Other recommendations from the Human Factors studies included fitting all windows in the mission support area with black out curtains and providing available in-house meal service and nap areas. While these recommendations were instituted, others, such as controlled transportation to and from sleep quarters, proved impractical to implement during the short duration (120 days) of nominal surface operations.

3. MISSION EXPERIENCE OF MARS TIME

The Mars Exploration Rover mission made a conscious decision to operate on Mars Time, and the resulting experience of the teams varied considerably. Of course, with approximately 250 MER operators working on Mars Time schedules, not all personnel will respond to the schedule in the same manner. For some, Mars Time was easy to maintain, while others found it to be a very challenging way to live. Many of the experiences we report here are consistent with literature regarding the impact of shift work on daily life [e.g., 2, 6]. Studies show that social-cultural issues are at least as problematic as physiological and cognitive considerations. Therefore, mission risk must be described by both the complexity of resulting operational processes and procedures, and the impact to personnel. We

discuss these concerns in light of the MER mission experience of Mars Time.

Local personnel vs. Remote personnel

In general, the Mars Time experience of personnel who lived all year long in the JPL vicinity (hereafter referred to as local personnel) was different than that of personnel who moved to JPL for the sole purpose of this mission (hereafter referred to as remote personnel). Notably, one of this paper's authors was local, while the other two were remote personnel who moved to JPL for the nominal mission. The experience of the authors is factored into this analysis as the authors were both observers and experimental subjects in the topic of Mars Time operations.

Personnel who moved temporarily to Pasadena from remotely located institutions, more specifically, the science team, generally had less difficulty working the Mars Time schedule. Special housing arrangements at local apartment complexes provided furnished apartments with black-out shades and flexibly scheduled cleaning services. However, as one team member commented, "It was difficult for housekeeping to understand that I really didn't want to be disturbed from 8 am to 4pm *every day*." (MER camera team member, personal communication) That is, the housekeeping staff did not follow a Mars Time schedule, and did not know the shifting needs of particular operations staff.

The experience of JPL local personnel differed from person to person, but overall, they found that Mars Time significantly impacted their personal lives. Because local personnel also had to manage time with their families, the added personal stress and conflict lead to a greater level of fatigue. For personnel who were married and both partners working MER, the situation was extremely stressful, as often there was no one left at home to manage daily tasks such as child and/or pet or parent care. At least one MER operator rented an apartment close to JPL and lived apart from his family when he worked MER shifts. He spent his days off back home with his family, much like individuals who commute and live between two cities. The recommendation from a MER team member, "Staff with childless, unmarried orphans." (MER uplink team member, personal communication) seems telling in the context of understanding the stressors on local personnel operating on Mars Time.

The fatigue of Mars Time may create risk and slow the pace of mission work and activity in daily life. One of the primary consequences of mental fatigue is that judgment is impaired, and affected individuals are not capable of making sound choices for their own well-being [6]. One local team member was injured after a series of Mars Time shifts when he mistakenly walked into a wall. Another local team member reported falling asleep at the onramp to the freeway. Fortunately, the authors know of no significant or long-lasting injuries resulting from the MER Mars Time experience. Arguably, these kinds of issues are regularly seen in professions that employ overnight and long shift

work, and cannot be attributed to the Mars Time staffing plan alone.

In contrast to remote personnel who temporarily relocated, local JPL personnel were sometimes allocated to a second task along with working operations for MER. Local personnel had to continue to attend institutional meetings. Personnel often ended up staying long after a shift to attend Earth time meetings related to other aspects of their work life. Operations staff also came in on their “days off” in order to attend to these kinds of responsibilities. Finally, professional travel, to conferences for instance, during MER Mars Time operations was difficult to schedule at best. Travel planning was challenging for all team members, as they were living on Mars Time but had to insert themselves in established Earth time flight schedules.

Local personnel also had to continue to fill out time cards. However, JPL time-keeping systems were not flexible enough to schedule more than 40 hours of work time, with 8-hour days. The time-keeping system could also not respond to the problem of operators working 4 days on, 3 days off, without a 2 day break for weekends. Negotiations were held, and this problem was eventually surmounted on a case-by-case basis.

Concessions and Adaptations to Mars Time

Working on Mars Time carried with it a notion that it was a “badge of honor”; people who were not ready to sign up for Mars Time were not truly committed to the project. This social status made working Mars Time hard to resist. “I’m working Mars Time all the time” was interpreted as staff members who had committed completely to the project. However, concessions were required, creating a number of special cases.

Some operations teams scheduled “discretionary” work time where staff was expected to be at work, but not necessarily operating a rover. In some cases, particular staff members’ needs were accommodated, such as the preference of one member to start and end his shift at as close to the same times of day as possible. This staff member rotated between spacecraft when the start and end times moved too far out of an acceptable range. Another staff member was uncomfortable working nights, so accommodations were made so that he worked as many day shifts as possible.

A schedule that mandated multiple, consecutive rest days was implemented to facilitate recovery from Mars Time operational shifts [e.g., 3]. However, the various operations teams implemented the schedule differently. One team chose to work 4 days on shift, 3 days off shift. Another team worked 7 days on, 7 days off. Some personnel stayed on Mars Time on their days off (MER sequencing team member, personal communication) while others moved back to Earth time on their days off. Some personnel attempted to live both Mars and Earth lives with limited success. It is because of the variation in implementation of Mars Time that it is difficult to provide a single coherent story regarding the effects of this staffing option.

Gastric distress is a main symptom of shift work, but it may very well be a side effect of this work, because it is difficult to know what meal to eat and when to eat it when starting a 2:30 AM shift. Eating times were personal and there were limited opportunities to share meals. Fresh, healthy food was not as readily available in the middle of the night. JPL meal services had to be modified significantly to accommodate Mars Time work, as there were few around the clock food resources in the nearby area. JPL provided a meal cart with food from the cafeteria during a specific two-hour block in the 24-hour day. The timing of the appearance of the cart shifted relative to the Earth day to take advantage of a potential lull in operations in the Mars sol at approximately midnight Mars Time. However, when the Mars sol shifted enough so that midnight Mars Time fell in Earth daytime, the food cart was not scheduled. The rationale was that the regular cafeteria was open in the daytime. Also, the food cart was unavailable when midnight Mars Time fell during the Earth day on a weekend, since local eateries were open during the daytime on weekends. Unfortunately, operations staff occasionally were confused about whether the cart would be present when they had a break as they were tracking multiple clocks simultaneously as well as working a schedule that did not follow the normal workday/weekend cycle (MER uplink team member, personal communication). Many operations staff brought large amounts of food with them and stored snacks and frozen foods in project-provided kitchen facilities. Free ice cream, provided as a reward for a successful mission, was also available to the team at all hours. Because the ice cream was easily available, operations personnel ate more of it than they would have normally (3-5 ice cream bars/day was not unusual). Some people gained weight. There is anecdotal evidence that team members relied on the ice cream as both a reward and a pick-me-up to push through the harder parts of their shift work.

The majority of issues described thus far reflect issues currently in the shift work literature. We turn now to a set of issues unique to Mars Time and the shifting asynchrony between Earth time and Mars Time.

Orbiting Spacecraft and Data Return Complexity

In some respects, Mars Time appears to have simplified the complexity of the operational processes. Mars Time reduced risk by maximizing the time available to generate a complete command cycle. Mars Time allowed for more frequent direct interactions between the ground operations team and the spacecraft. When rovers exhibited anomalous behavior, Mars Time simplified the team’s ability to respond. Key personnel could extend their shifts to resolve problems. Finally, both the clock and direct communication passes (Direct to Earth, or DTE) were in synch with the work.

Mars Time also made it possible for personnel to understand what was currently occurring on the spacecraft (taking into account the one-way light time travel delay for returned information from Mars). It remains to be seen whether this state knowledge is always necessary to the successful operation of a spacecraft, but working in synch

did help the operations team establish a bond with the vehicles on Mars.

The original MER mission timeline was designed to utilize DTE communications, which was expected to provide the data necessary to make each sol's decisions. However, most data for MER was relayed to the Earth team through orbiting Martian satellites rather than DTE. The satellites had to be in accurate orbital positions to capture the data from the Martian surface as well as to transmit it to Earth. Transmission latency occurred as the satellites orbited to reposition themselves for each of these tasks.

On Mars Time, the assumption was that the DTE data would be available to make decisions for each sol. While the team was not supposed to hold decision processes for the return of particular data, the natural inclination was to hold off on decision-making where possible so that the most recent information could be incorporated. Because most data were returned by relay, the team often had to wait for longer periods for this data to be returned before making decisions. Sometimes this had the effect of delaying the work process, resulting in last minute decision making and pressuring the team to complete tasks in shorter than planned times.

During operations, data return times were not set on precise schedules but rather occurred during "windows" of opportunity, Mars Time staffing could not decrease the complexity introduced by these transmission latencies. For example, on each sol data was examined when the operations staff came to work on their Mars Time shift. This might be hours after the actual receipt of the data by the mission. If the time differential between receipt of data and data analysis was particularly extensive, it could draw down margins in the daily planning and command load cycle causing pressure on the timeline. Latency made it much more difficult to optimize data return events. In section 5, we discuss the relationship between Earth time staffing (during MER extended mission operations) and data return latency.

Mars Time personnel worked schedules that were difficult to remember and predict beyond a day or two in advance without the aid of carefully prepared electronic schedules. We address in detail the issue of keeping track of schedules as well as several different times in Section 4.

4. KEEPING TRACK OF TIME

MER mission personnel working on Mars Time had to keep track of several different kinds of time and coordinate those times with work staffing schedules. Some of the different time and coordination issues were:

- Tracking Mars Time within a mission in order to plan rover activities relative to Martian daylight and send commands to the rovers in a timely fashion.
- Tracking both Mars Time and the equivalent Earth time in each mission so that personnel could keep track of events inside and outside the mission while they were working.
- Coordinating time between the two missions for sharing Mars communication infrastructures and sharing mission facilities.
- Scheduling of work within a sol so that participants completed each phase of work and handed over to the next team within the mission timeline of events.
- Scheduling of work to identify both the consistent Mars start time for shifts as well as the constantly rotating Earth start times for the same shift so that personnel knew when to show up for work.
- Identification of long-term staff schedules so that personnel could keep track of their schedules relative to both Earth and Mars Time over extended time periods and when planning for days off.

Working on Mars Time, personnel had to track both the Martian Local Solar Time (LST) as well as the Martian date (Sol number) and coordinate those times with Earth Pacific Standard Time (PST), the Universal Time (UTC) also known as Greenwich Mean Time (GMT), and the current Julian calendar Earth day and date.

The two rovers were working on opposite sides of Mars, at the Meridiani Planum and Gusev Crater sites. While this difference facilitated easier recollection of rover-specific issues, it doubled the time challenges as the work of the two rovers took place in different Martian time zones. MER A, the Spirit mission at Gusev Crater, and MER B, the Opportunity mission at Meridiani Planum, had different times known as LST-A and LST-B. Whether personnel were working on the Spirit or Opportunity missions, they had to know what time it was on their particular area of Mars and make translations between Mars and Earth time with ease. While daylight and darkness helped staff keep track of Earth time to some degree, there were no environmental clues to help track Mars Time.

Additionally, science team personnel who had moved to Pasadena for the duration of the mission from an institution in another time zone had to keep track of the time in relation to their "home" time zone. A mission tool, the Collaborative Information Portal (CIP) [7] had clocks that were designed specifically to allow personnel to configure and track all of these times as needed. For instance, participants could track and compare LST-A and/or LST-B, track and compare Mars Time with PST or with time in another Earth time zone, and track UTC (universal time coordinated). Figures 2, 3 show two such configurations of the CIP clocks displayed on another mission tool, the MERBoard [8]. The large display of these configurable clocks on the MERBoard became an essential work practice, facilitating work on the mission time line.



Figure 2. CIP clock configuration, as it appeared in surface mission support area on Apr. 1, 2004, with generally similar information on the right and left screens. The top line (shaded blue) indicates the Sol for MER A and the local solar time. The next line (shaded green) indicates the Sol for MER B and its local solar time. The third and fourth lines provide earth times, for Los Angeles and UTC. The CIP clocks allowed users to toggle the time systems by using pull down menus to the right of each line.

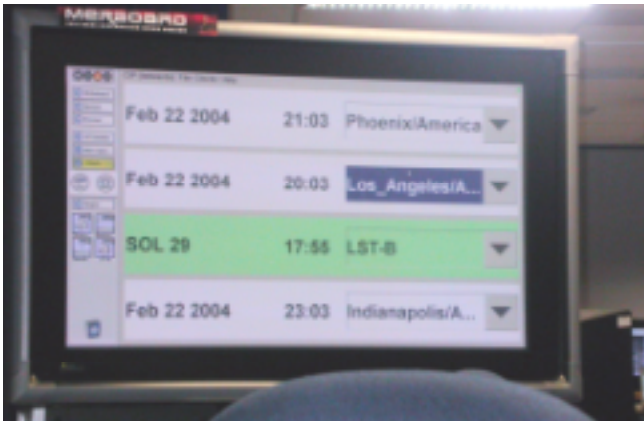


Figure 3. CIP clock configuration, as it appeared in the science area for MER B on February 22, 2004. The first and second lines provide Earth times, for Phoenix, AZ and Los Angeles, CA. The next line (shaded green) indicates the Sol for MER B with its local solar time. The final line shows Earth time in Indianapolis.

Staffing schedules had to indicate both Earth and Mars shift start times (Figure 4). While the start of Mars Time work might always be 1400 hrs LST, the fact that the related Earth time start of work “walked forward” by approximately thirty-nine minutes each day forced teams to create elaborate schedules to coordinate work. While it was intuitive to personnel that they needed to report approximately thirty-nine minutes later for work tomorrow, it was not intuitive or easy to track an approximately thirty-nine minute change

over even short periods or when planning events several days or weeks ahead. It was also extremely easy to lose track of the time rotation when taking days off between work periods. Even just a few days off made it difficult to project ahead and determine Earth time relevant to a particular time on the Martian clock. For example, to ensure getting to work on time, two of the authors felt compelled to write start times for every Mars day on their Earth calendars and consider the changing traffic patterns in deciding on when to leave for work. Further, updates to schedules were difficult to track. Often, email was used to distribute versions of the staffing schedules, which suggests that staff members must check their email at the right time (either at home or at work) to ensure that they were aware of schedule changes.

MER A				
Date [PDT] @ PDL Shift Start	1/5/04 15:08	1/6/04 15:48	1/7/04 16:27	1/8/04 17:07
Approx. Sol	3	4	5	6
Pancam PEL	JBe	JBe	JJo	JJo
Pancam PDL	MLe	MLe	RMo	WFa
Pancam PDA	JSo	FSe	FSe	MJo
Pancam PDA2	MWo	WFa	MJo	JSD
Pancam PUL	JPr	JPr	HAr	HAr
Pancam PUL2	EMc	MBM	JPr	MBM

Figure 4. Section from one of the science team schedules showing mission (MER A), staff positions, i.e., “Pancam PEL” (Panoramic Camera Payload Element Lead). Initials indicate the staff member. The schedule shows the Earth date and time as well as the associated Martian Sol for each shift start. In this document, version control for staffing changes is shown by red text (here, FSe). Interestingly, the associated Mars Time start time (1700 LST for instance) for shift work starts only had to be displayed once on the schedule (not shown here) as the Mars Time shift starts were fixed relative to the Martian sol and did not rotate during the nominal mission. (Courtesy of J. Bell, MER Pancam PEL)

Many operations team members worked more than one position and thus had schedules from more than one position manager. It was difficult for personnel to coordinate these schedules across positions. Although team members recognized the need to create an integrated scheduling and staffing tool, higher priority concurrent needs hindered the implementation.

Many mission participants invested in special analog watches, called “Mars watches,” that were adjusted to keep Mars Time. The watches were extremely helpful, because a glance told personnel that they had three Mars hours before they had to show up at a 1400 LST meeting or start of shift. The limitation of the watches was that if one went off Mars Time for several days and did not pay attention to

mission events, it was impossible to know if the analog watch, without a 24-hour time (military time) display, was indicating morning or evening times, one could not just look out the window and tell if it was dark or light on Mars. In general, use of Mars Time reduced the cognitive load on mission personnel because the team did not have to translate task completion times into rover need times. However, other time translations still occurred; participants had to translate time differences in setting their personal alarm clocks to estimate the appropriate Earth time each day to get up to meet the Mars time schedule. The analog Mars watches did not have alarms.

While some analog wall clocks displayed both 24-hour time (military time) and PST (Figure 5), they did not indicate whether the time on the clock was morning or evening, 0700 or 1900 hrs) or whether it was day or night on Mars.



Figure 5. Since mission Earth time was kept in 24-hour time (military time), workers also had to translate PST to 24-hour time (military time). A few clocks in the mission support facility helped with this coordination.

The number of necessary, relevant time conversions at each point of work in the Earth day and Martian sol was complex. As shown in Fig 2 and 3, different teams needed different representations of particular time sets depending on the nature of their work. Teams began to leave these specialized representations as persistent CIP displays on the MERBoards, indicating the value of such “clocks”.

Early on during the mission design phase, the authors recognized many of the problems that would be involved in tracking and translating time and coordinating the various “times” with associated work and schedules. They made recommendations for specialized clocks and schedules to support mission operations.

5. EXTENDED MISSION OPERATIONS

The MER mission moved from nominal to extended mission operations after successfully working for ninety days/sols (the definition of mission success) with each rover. At this time, the teams also transitioned to “Earth time schedules”. With the onset of extended mission, many science team members also returned to their home institutions creating distributed work and teams. Based on the switch to Earth time and the nature of extended operations, we can look at the operational effects of Mars Time from yet another perspective.

During the nominal mission, science and engineering participants could refer to a set schedule of work events that, once determined, rarely, if ever changed unpredictably. With the shift to Earth time operations, MER teams still had to work in relation to the timing of pre-existing Mars events, including uplink and downlink opportunities. This precluded simply moving to permanent, regularly scheduled Earth business hours. Instead it required the mission to create shifting schedules that allowed people to work in Earth time but still maximize synchrony between Earth and Mars Time. Shifts started later over time, but it was not clear on what day the shift would move to a later time. Because the shifting schedules were unpredictable, local and remote participants had to check an e-mail schedule to confirm meeting times. However, participants could not be sure that they had received the most recent update in their e-mail, creating substantial opportunity for confusion.

The shift from Mars Time to Earth time also required a compressed science planning process. This affected the planning process in many ways. Science teams consolidated the work of both rover operations within a single daytime schedule, offering them the opportunity to unite in a joint meeting. However, on occasion, managing the asynchrony for both rovers made it impossible to identify a feasible joint meeting time, again contributing to schedule uncertainty.

In order to coordinate the drifting Earth and Mars Times, at some point in the shifting schedule process, a dramatic re-synch was required. In the re-synch, instead of starting the day later, participants would start the day much earlier. These days were called “transition days”, and potentially reversed the order of activities. Prior to transition, downlink may have occurred at the end of the shift. When modest shifting could no longer keep the downlink in the window of one workday, transition days restored the downlink event to the beginning of the shift. Thus, if the timing of the communication event varied within the workday, the organization of the related work also varied. A new type of sol also emerged. So-called “restricted sols” are those in which downlink is not available before planning so planning had to incorporate work for two sols ahead.

Chasing the Downlink Data Return

When staffing to Earth time, the issues related to data latency take on a different character. On Earth time, there

was no expectation that the downlinked data would arrive in time to influence the decision process. Therefore science planning was less dependent upon immediately-returned data and instead relied on the data already in hand. We argue that Earth time staffing makes the planning more realistic by not expecting the team to perform “11th hour miracles” that require the completion of tasks in far less time than called for in the process.

When the vehicles first began operating on Earth time, the Opportunity science team appeared to be chasing the downlinks, postponing the refinement of a single plan until after a crucial planning meeting (the Science Operations Working Group or SOWG) in an attempt to continue the practice begun in the nominal mission of waiting for downlink information. As the time of downlinks continued to diverge from the work of Earth time operations, however, this strategy was not sustainable. Adaptations in response to late arriving data could not be incorporated into the planning process with sufficient speed to meet the uplink so participants began to move from reactive planning to predefined, relatively context independent, multi-sol plans. Planning began before the arrival of new data, resulting in more generic plans. However, during periods of heightened interest, the science team reverted to semi-Mars Time in order to react to the latest data.

6. CONCLUSIONS

The MER mission’s desire for complete flexibility in sequencing the rovers on Mars, as well as the ability to maximize the availability of co-located operations personnel led to the decision to staff on Mars Time. The nature of future missions however, will dictate different assumptions about the nature of tele-operations, including the length of the mission, the particular software tools being used, and the nature and amount of autonomy being used. It is likely that each mission will consider these assumptions relative to any possible staffing options when deciding on the nature of tele-operations of remote spacecraft. Depending on each missions design, it may not be necessary to work on Mars Time, despite the obvious mission advantages to MER.

We suggest that if MER had had the resources (primarily time) to significantly cross-train the operations team on both uplink and downlink tasks, then much of the need for Mars Time staffing could be eliminated. Operations might still require 24 hours/day staffing, but personnel could maintain a regular shift schedule and perform whichever task was required on Mars when they came to work on their Earth time schedule. Without cross training, the Mars schedule determines the tasks available to a particular operations staff. While training for single positions is often difficult in the rapid development environment of a space mission, in future long-duration, extended (1 year and more) missions, staff cross-training should be possible.

Cross training is appealing in multiple ways; fewer operations staff would be required, and operations team members should be able to trace a process from end to end, that is from uplink request to downlink data receipt. The traceability reduces risk because the “corporate knowledge” is managed better, and also produces a feeling of ownership in operations teams over a particular segment of the job. Also, some operations tasks may be more tedious than others, and cross-training provides a stimulation and new feel to the operations tasks over time. It may prove to be true that certain specialized tasks will still require operations staff to follow Mars Time, but the burden may not be as great on the entire operations team.

Additionally, we suggest that deficiencies in automation, and tool integration optimization impact staffing needs. That is, if tools can be developed to support shorter turn-around time of the work from data-receipt to command-upload, then Mars Time staffing is less important in maximizing rover resources and the work could be done on an Earth time schedule.

Implications for Mission Management

A number of institutional challenges should be addressed when considering Mars Time staffing.

- Institutional time-keeping policies and food services should be negotiated to accommodate the 24-hour, 7 days per week staffing.
- While schedule personalization is a significant challenge faced by management in charge of scheduling, it is unlikely that all customization can be eliminated. Mechanisms such as scheduling tools should be considered to help address this issue.
- Better mechanisms for schedule distribution should be considered. Email distribution is limited by issues of server latency, versioning, and intermittent participant access to emailed notifications.
- Management should also consider scheduling “discretionary” time as part of the mission work time so that personnel have Earth daytime hours to complete other non-operations work such as attending staff meetings and seminars.
- Flexible yet persistent representations of time (clocks) need to be easily available to operations staff both at home and in operations workspaces.

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8. BIOGRAPHY

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