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Operational Lessons Learnt from the 2013 ILEWG EuroMoonMars-B Analogue Campaign for Future Habitat Operations on the Moon and Mars

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Abstract. This paper discusses operational lessons learnt from the 2013 EuroMoonMars-B (MDRS crew 125) analogue campaign for future habitat operations on the Moon and Mars. The two-week campaign conducted a series of geologic, technological, operational, and human factors research toward the goals of the International Lunar Exploration Working Group (ILEWG). The results from those operations provide recommendations for future crewed expeditions for increasing the science return based on improved resource allocation and crew habitation.

1 Introduction

The four-week long International Lunar Exploration Working Group (ILEWG) EuroMoonMars 2013 campaign conducted a series of operations, human factors, and scientific exploration research primarily in the operations of conducting field geology to identify targets of astrobiological interest [1, 2]. This campaign followed a series of field campaigns organised by ILEWG and partners at the Mars Desert Research Station (MDRS) in order to validate technologies in the field [4, 5],to perform Moon-Mars geological and astrobiological research [3], to study human factors [16, 13, 10], to train students, and promote space science and exploration.

EuroMoonMars-B (MDRS Crew 125) was the second rotation of that campaign to take place at MDRS, shown in Figure 1 immediately following the EuroMoonMars-A group. The two-week campaign was a human Mars mission simulation focused on the area surrounding MDRS as a terrestrial analogue for Gale Crater on Mars. Gale Crater features evidence of several geological features that are commonly preserved and exposed in terrestrial desert environments: sedimentary rocks deposited by fluvial activity, inverted channels,

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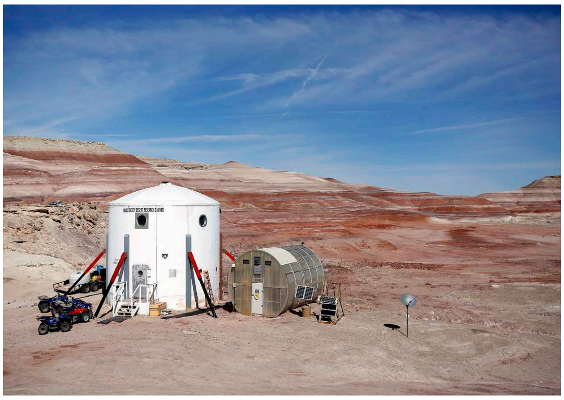

Figure 1. *The Mars Desert Research Station (MDRS) is located near Hanksville, Utah. It consists of the main habitat and work space called 'the Hab' (centre-left), a greenhouse called the 'GreenHab' (centre), and the Musk Observatory (not pictured). Electrical power is generated on site, and fresh water is supplied from Hanksville. Other equipment available for use is the 'Hab car' to drive to and from Hanksville, and five all terrain vehicles (ATVs) (left) for use on extra-vehicular activity (EVA). Picture courtesy of Jim Urquhart/Reuters.*

Figure 2. *Crew members were required to wear the EVA suits while in simulation at MDRS. Preparation for EVAs often required a significant amount of time to test radios, put on suits and pack sampling equipment. Picture courtesy of Jim Urquhart/Reuters.*

and concretions. All of these features are present in the desert region surrounding MDRS, and have been observed on Mars from either orbital imagery [7] or ground-level imagery from *Curiosity* [15]. These geological features are also potential indicators for past liquid water and may provide evidence for life.

The campaign included geologic studies of the region, and crew psychology studies. Additional studies in human-rover interaction, operational efficiency, technology demonstration, and human factors were also conducted. In all, EuroMoonMars-B completed more than 12 core objectives. The results of these studies provide insights into how future crewed campaigns can improve scientific outcomes, how simulation design can improve the realization of scientific objectives and the overall mission experience, and how habitat design influences such scientific campaigns.

This paper focuses on the operational aspects of this campaign; scientific objectives, where they influence the operations, are presented in brief. Scientific results are described in more detail in companion publications [8, 9, 1, 2].

2 Scientific and Supporting Activities for Gale Crater Analogue Mission

The operations of the analogue campaign were planned to what is believed to be similar to human exploration at Gale Crater. Scientific studies, technology demonstrations, and additional crew activities to support the operations of the campaign were conducted in parallel. These additional studies and activities are provided in the following sections. The overall scheduling of these activities is described in Section 3.

2.1 Geologic Studies for Gale Crater Analogue Mission

Orbital imagery was studied to identify macro-scale targets of interest and then extra vehicular activities (EVAs) were conducted at these location to identify micro-scale targets of interest. The summary of the geologic studies, which are further described in [9, 1, 2], are given in the following list and reference EVA numbers and locations provided in Table 1:

- **MDRS analogues of Gale Crater sites:** Specific areas were selected based on remote sensing data that looked similar to Gale Crater. Those areas were visited on EVAs to take panoramic context and up-close images of targets of interest. EVAs 3 and 5 at location B supported this study.

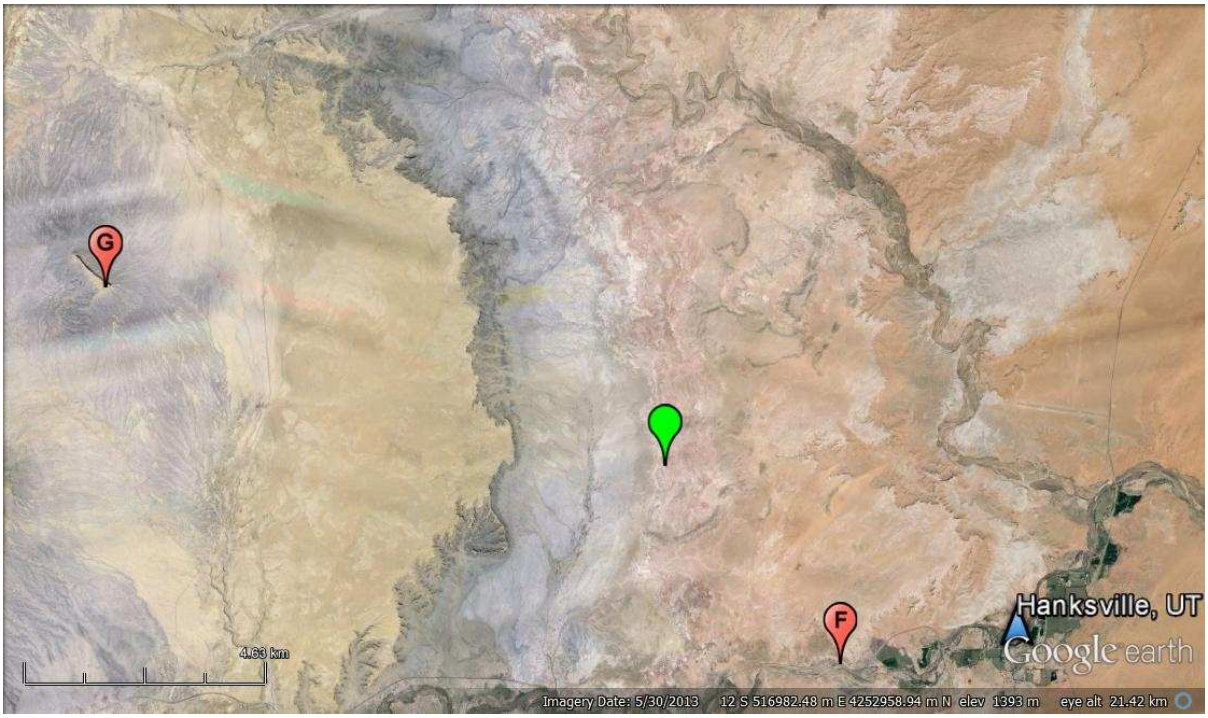

Figure 3. *Regional map view of MDRS (located at the unlabelled green flag) and EVA destinations. Also shown in the relative location of Hanksville, UT.*

- ***Curiosity* data comparison to MDRS:** Using ground data from *Curiosity* and images from the previous item, EVAs were planned to collect data to support additional geological experiments listed below. EVAs 3 and 5 at location B supported this study.

- **Sulphates from orbit / surface:** Sulphate-bearing mineral samples were collected at sites known to contain sulphate minerals from previous work. X-ray diffraction mineralogy data was compared to UV-Vis-nIR data as a proxy for orbital data to determine usefulness of orbital spectral data at Martian sites similar to those studied. EVAs 3 and 5 at location B, and EVA 11 at location F supported this study.

- **SediChem experiment:** The Morrison Formation Brushy Basin Member was examined to find terrestrial concretion analogues to those found in Gale Crater. EVAs 1,2, and 9 at location A; EVA 4 at location C; EVAs 6 and 7 at location D; and EVA 8 at location E all supported this study.

- **Vertical survey of hills and mesas:** Small hills near MDRS were surveyed for observable differences on the surface with imaging with resolution of 1-5 mm. The survey produced a series of images from the bottom of the hill to the top with context to up-close images to analyze the types of differences observable at these resolution scales regarding accumulation and erosional processes, dust coverage, characteristic particle sizes and shape, cementation signatures, aeolian or fluvial runoff and mass wasting erosional styles. EVAs 3 and 10 at location D supported this study.

- **Cryptobiotic crust experiment:** Similar to the above study, cryptobiotic crusts were examined at varying distances to identify visual differences from near to far. EVAs 1 and 2 at location A supported this study.

- **Sample analysis for astrobiology** Astrobiologically useful samples were collected from ash-bearing layers in Factory Butte for post-campaign analysis to test potential instruments to be flown on *Exo-*

Figure 4. *Regional map view of MDRS (located at the unlabelled green flag) and EVA destinations.*

Mars. EVA 12 at location G supported this study.

The EVAs for support of the Gale Crater analogues investigation were a central part of the operations at MDRS and dominated the daily schedule. Table 1 lists the EVAs in chronological order, and provides references to the destinations relative to MDRS in Figures 3 and 4.

2.2 Habitability and Sound Study

The habitability study of the 2013 ILEWG EuroMoon-Mars-B campaign was an ongoing research project since 2010 that is focused on psychological, physiological, environmental, socio-cultural, and operational human factors that may impact space missions [11, 13, 16, 10].

The research was aimed at finding a methodology for the improvement of safety, performance, and comfort by optimizing human factors. Different kinds of research were developed for analyzing human factors by means of habitability debriefings and by experimenting with sensory and creative stimulation, such as artistic performances or sound and music.

The habitability debriefing is a special instrument developed by Schlacht [10] to analyze problems and find solutions in order to optimize the interaction between the human and the system. The debriefing has two main innovative characteristics: it analyzes all the human factors, and it does this with the entire crew discussing them together.

As a result, the crew reported mainly operational problems connected with psychological factors (Table 2, from [8]). In particular, it validated the results of previous crew, which had reported 'communication' as the most relevant factor to be improved to increase mission safety, performance, and comfort (Table 3, from [8]).

The research during the EuroMoonMars-B campaign also investigated pleasant sounds as countermeasures to stress caused by living in isolated habitats and settlements in extreme environments, such as those encountered in crewed space missions. Reducing stress is one key factor in keeping the crew healthy and productive during the mission. Stress may impact immune systems and reduce crew performance [6]. Loss of productivity due to stress and related health problems, such as insomnia, depression and fatigue, will impact the ability to adhere to the detailed mission plan and meet the mission objectives. The result may be additional stress placed on other crew members as the schedule begins to

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EVA #	Location	Flag
1	Kissing Camel Ridge	A
2	Kissing Camel Ridge	A
3	Lion's Den Canyon	B
4	Hab Ridge	C
5	Lion's Den Canyon	B
6	Stegosaurus Ridge	D
7	Stegosaurus Ridge	D
8	Dakota Sandstone	E
9	Kissing Camel Ridge	A
10	Stegosaurus Ridge	D
11	Coal Mine Wash	F
12	Factory Butte	G
13	Crowdsourcing EVA	1-5

TABLE 1. *List of the EVAs during EuroMoonMars-B. The icon refers to the letter or number on the labelled flags on the maps shown in Figures 3 and 4. The locations listed are colloquial names and not an official geographical place name.*

FIGURE 5. *Active musical engagement was a form of creative outlet among the crew to help foster a positive working and living environment. © Ayako Ono 2013*

erode. It is therefore important to assess simple operational changes, such as designing a pleasant soundscape (sound design of the habitat) to help mitigate increasing stress. Additional multidisciplinary activities to reduce stress were also explored, such as active musical engagement shown in Figure 5, variation of pleasant sounds, and creative activity such as meal preparation and the creation of a 'Mars Zen Garden' shown in Figure 6.

The 2013 EuroMoonMars-B investigation on soundscape concluded on the basis of questionnaire analysis that passive music, active music and sounds of nature had positive effects on group dynamics, well-being, and in reducing stress from noise [17, 8]. However, different approaches are needed because music and sounds of nature may not always be effective in reducing stress especially related to communication issues. Considering that habitability within soundscape design may be even more important for long-duration space missions, the habitability study also increased the crew's awareness on the relevance of habitability factors providing some baseline data and a methodology for further investigation in long duration missions.

2.3 Lunar SimComm Demonstration

Bandwidth is limited when communicating to space, and also at MDRS. The satellite connection provided by the *Mars Society* at MDRS has daily data cap of 100 MB and at times suffers from small, variable delays and slow, variable speeds. One aspect of scheduling and operations planning was to consider internet as a limited resource that needs to be managed. Some days required greater amount of data, in the form of reports and photos, to be uploaded against the data cap. Accidental or intentional usage of high data-consuming computer applications, such as video conferencing or, large file downloads, needed to be accounted for in daily internet monitoring. The ability to communicate aurally and visually, in additional to textually, with mission and science support would be an improvement over the current text-only approach. However, type of communication should not impact the volume of science data to be delivered. With these communications limits in mind, the Lunar SimComm demonstration was performed to test a low-bandwidth communication platform.

VeaMea, from 2014 known as swyMe, is a participating company in the European Space Agency's technology transfer programme located in The Netherlands. They are developing software to broadcast and receive video and audio at high quality but at low bandwidths. This investigation in particular could be of benefit both technologically and is interesting for outreach purposes. This software was tested during EuroMoonMars-B between MDRS and the European Space Innovation Centre (ESIC) in The Netherlands. The objective was to demonstrate the possibility of low-bandwidth, delay-tolerate video communications over time-delays encountered between Earth and the Moon.

The first demonstration was to test the satellite Inter-

Field	Crew	Problem	Solutions
Operational (psychological) IVA	5/6	Mission support information flow (communication)	1. Psychological screening 2. Education on support
Operational (physiological)	4/6	EVA suit design	1. Use modified motorcycle helmet (safer) 2. Use small suits
Environmental, IVA	4/6	State-room temperature	1. Individual thermal control 2. Isolate heating pipes
Operational (Psychological) IVA	4/6	Outdoor Toilets (safety, psychological discomfort, wasting time)	1. Fix indoor toilet 2. Have real tunnel

Table 2. *Habitability debriefing for Crew 125 [8], which includes identified problems and proposed solutions. The approached fields are operational, psychological, socio-cultural, physiological, and environmental. The crew ratio represents the number of crew members that find it relavent to the total number of crew members. IVA is Intra Vehicular Activity*

Topics approached	Crew:	91	100a	113	124	125	143
Communication	5/6		x	x	x	x	x
Interior setting	5/6	x		x	x	x	x
Toilet	4/6	x	x		x	x	
Food (Nutella ®)	3/5	x	x	x			
Music	2/6	x	x				
Gymnastics	2/6	x	x				
Storage	2/6	x		x			

Table 3. *Debriefing summary for 2010 to 2013 habitability study [8, 12], which includes all approached fields (Operational, psychological, socio-cultural, physiological, environmental)*

net connection before conducting a live video conference. The initial demonstration showed that two-way communication was possible, and so an outreach event was organized at ESIC to demonstrate VeaMea's software. A 30 minute video conference was established between the EuroMoonMars-B crew at MDRS and an audience at ESIC. Also, three-way communication was established with remote support by Dr. Schlacht in Berlin, who was able to watch the visual communication and listen to the audio communication between ESIC and MDRS, and interact with ESIC. The crew introduced themselves and gave an explanation of the activities at MDRS. The audio and video quality was high and the technology self-corrected the occasional time-delay. A total of 5 MB, as measured by the satellite Internet monitor, was consumed for the 30 minute video conference, which was deemed a remarkable achievement by the crew.

The tested software proved to be an efficient form of communication without prohibitively increasing the Internet bandwidth consumption. Its current commercial use is in tele-medicine and tele-health, and enterprise video conferencing. This software, which is based on patented space technology, has been recommended to the Mars Society to be used at MDRS as it would enable improved communication between the MDRS crew and Mission Control.

2.4 Robotic Field Assistants

A key objective to sending humans to conduct field geology, or to explore another planet, is to increase the possible scientific return. A driver for that objective is to improve the efficiency of those humans such that they spend a greater portion of their time conducting their core science activities and reduce the burden of otherwise secondary activities. Much of the operations planning and scheduling centred on the execution and support of EVAs. Each EVA had a time allotment to conduct the EVA, and additional time allotments for supporting activities and preparation. A particular challenge for operations planning is scheduling sufficient EVAs to achieve the mission objectives. As each site

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Figure 6. *The tabletop 'Mars Zen Garden' was one example of creative outlets during EuroMoonMars-B. © Ayako Ono 2013*

investigation has more available targets than time permits, it is essential that an investigation is performed efficiently so as to not impact the scheduling of other site investigations.

It is believed that robotic assistants and task automation would be valuable tools in order to meet the target of improved EVA efficiency in terms of time and personnel utilized to complete site investigation. During EuroMoonMars-B, the field geologists were observed and recorded conducting their site investigations and sample collections to assess common activities that could be off-loaded to robotic assistants or automation. The test cases investigated during EuroMoonMars-B indicate savings in crew time are achievable; the number of EVAs spent on a given science objective could be reduced allowing for additional science objectives [2].

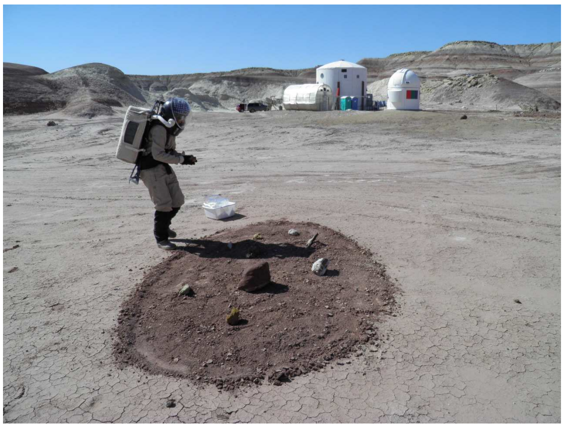

Figure 7. *A 'Mars Zen Garden' was created outside the Hab at MDRS. This Zen garden was a larger outdoor replica of an indoor tabletop Zen garden (shown in Figure 6) and one example of creative outlets performed during EuroMoonMars-B. © Ayako Ono 2013*

3 Mission Scheduling

Planning for the operations to support the mission objectives began in advance of the EuroMoonMars campaign. EVA proposals and desired experiments to support the mission objectives were collected along with estimates of the time they required to complete. All of these proposals and time estimates were synthesized into a daily mission plan. The schedule needed to be sufficiently flexible to account for changes to the schedule due to new science targets, unforeseen maintenance, and additional demands on the crew. The schedule would be continually iterated throughout the mission duration, however the baseline served as an action item list for each day and incorporated the essential daily tasks such as meal preparation and maintenance. A secondary objective for the detailed schedule was to investigate post-mission how well the mission adhered to the initial schedule, and to what extent unforeseen issues required time to resolve. The mission schedule was discussed, prepared and iterated during the mission by the commander and executive officer days in advance and then discussed with the whole crew during briefings.

A table was set-up that included columns for each crew member in order to plan and record the daily schedule, and columns noting general crew tasks or allocations. These general crew tasks included meal preparation, engineering checks, reporting and communication with mission support; allocations included where

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Date: March 1, 2013 (Sol 7)
Weather Forecast:
Summary: Ayako Questionaire + EVA to inverted channels

Time	General Task	EVA Tasks	Crew Tasks	Commander Melissa	2IC/ Hab Engineer Volker*	Rover Engineer Matt	Scientist Hans	Geologist Csilla*	Human Factors Ayako
07:00									
	Exercise (optional)								
08:00	Breakfast								
	Briefing								
09:00			Curiosity		Dishes				
			images	Questionaire Exp.		Playing with androids	Orbital images	Orbital images	Questionaire Exp.
10:00				Orbital images/ Questiona	Questionaire Exp.				Questionaire Exp.
				Orbital images	Questionaire Exp.			Questionaire Exp.	Questionaire Exp.
11:00				Mission scheduling	Pump OR Microharvester		Questionaire Exp./ no quest	Outreach	Questionaire Exp.
						Questionaire Exp./ no questionaire			Questionaire Exp.
12:00				Science stuff					
				Lunch prep	Eng Round				Lunch prep
13:00	Lunch								
14:00				EVA prep	EVA prep	Dishes	Dishes	EVA prep	EVA prep
				EVA prep	EVA prep			EVA prep	reporting
15:00						Playing with androids	Greenhouse		Exp. Prep.
									No EVA
16:00				EVA #6	EVA #6	HABCOM	HSO	EVA #6	EVA #6
				Inverted Channels	Inverted Channels			Inverted Channels	Inverted Channels
17:00							Photo organizing		?
18:00				post-EVA/ EVA	post-EVA/ EVA	Dinner prep	Dinner prep	post-EVA/ EVA	post-EVA
	Dinner								
19:00									
	Briefing				CDR Check-in	CAPCOM			
20:00			Report		Dishes/ no dishes		Observatory prep		Dishes
			writing		Pump repair		Pump repair		
21:00							Observatory /no obs.		
22:00									
23:00	off duty								
00:00									

Figure 8. *One example of a daily schedule for EuroMoonMars-B with colour codes marking important blocks of the schedule.*

the majority of the crew would be, EVA time allocations, and EVA tasks. Furthermore a colour code for certain blocks of actions was set-up to enable an easier identification in the schedule. The following colour-codes have been used:

- teal: Beginning of daily schedule (usually with exercise)
- light red: Briefings, i.e. mandatory for all crew
- orange: EVA time allotment
- blue: Report time (for reports to mission control)
- green: Meal times, usually taken as group

These blocks were marked to emphasize importance, e.g. the report time was mandatory for all crew members, depending on function, as reporting to mission control was time-sensitive and essential. Reports included summaries of the day from the Commander, Habitat Engineer and regarding the individual experiments and EVAs run during the day. Progress and condition of either experiments or the habitat were reported.

In the morning briefings a short summary of the day as planned was presented to the crew, where necessary adaptations were made. The evening briefings were used to plan the remaining day (e.g. review of geological samples) and the coming days and discuss issues with the crew. Adaptations to the schedule were made as necessary. On each morning the schedule of the day was placed at the wall of the habitat's crew area for display to the crew. An example daily schedule (here 7th mission day) is given in Figure 8. Activities were planned in time slots of 30 minutes, which was regarded as a useful compromise between detail and clarity.

During the day changes to the schedule were also noted to allow refinement of the scheduling process. These changes were noted in the schedule with red font colour, to distinguish them from the planned actions in

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black font colour. This is also visible in Figure 8. Essential roles, such as the capsule communicator (CapCom), who was the main contact person with Mission Control during communication windows, were marked as well for each rotation. For each day an asterisk behind two names denotes turns in showering allowance, which was one 2 minute shower every three days per crew member. Regarding individual tasks of the crew members, only transition to a new task is marked in the schedule, i.e. the previous action is assumed to last as long as no further action is marked in the schedule.

3.1 Meal Preparation

Meal preparation and clean-up for 6 individuals was a time consuming endeavour that required careful scheduling into the daily operations plan. Meals needed to be of sufficient quality to for both nutritional requirements as well as crew-well being, and as such required adequate time to prepare. The scheduling of preparation and clean-up tasks was such that those tasks did not interfere with EVAs. Crew members that had afternoon EVAs did not do clean-up after lunch nor dinner preparation as those tasks would interfere with EVA timing. Also, returning EVA team members would often be fatigued, and were required to complete EVA and science reports ahead of the mission support communication window, which itself would begin during the dinner period shortly after the EVA conclusion.

The crew was supplied with a fixed amount of food to last for the 2-week rotation. Left over food from previous crews was also available in the pantry. While there was more than enough available calories from food to sustain the crew for the 2 weeks, highly desirable food items needed to be rationed such that adequately enjoyable meals could be had until the end. An informal food allocation plan was established to meet this objective. Certain days that were projected to be particularly demanding were targeted for quick leftovers, and thus quick clean-up, from the previous day. Days that had EVAs that were projected to be particularly fatiguing were targeted for highly enjoyable food items. A mid-rotation 'feast' and a celebratory departure morning breakfast were allocated special food items.

The meal times served a dual purpose in that they were the only times that all six crew members were together, as shown in Figure 9; in addition to eating and socializing, the meal times were allocated for crew meetings. Breakfast served as the daily briefing and review of mission objectives. Lunch served as a review of the morning's progress and results from EVA, and also a pre-EVA briefing. Dinner, which coincided with the mission support communication window, served as the daily debrief and planning meeting for the following day. It was also the time to review the mission objectives in context with the preliminary schedule.

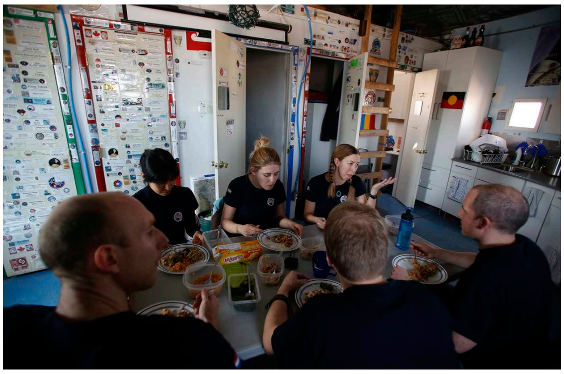

FIGURE 9. *Meal times were the few times during the day that all six crew members were together. Meal times were opportunities for both socializing and meetings. Picture courtesy of Jim Urquhart/Reuters.*

Generally, meal times allowed for some flexibility to be built into the schedule. As meal preparation was a secondary task, it allowed for scheduling conflicts to be relieved without significant impact to the overall mission. Crew members who had completed their required tasks could be reassigned to meal preparation and clean-up in place of another crew member who had incomplete (e.g. delayed EVA return, report writing) or unplanned (e.g. maintenance) tasks to complete.

3.2 GreenHab and Other Maintenance

The GreenHab is a greenhouse next to the Hab. It contains a variety of plants, as shown in Figure 10 requiring daily care, and the GreenHab itself requires daily maintenance and monitoring to ensure optimal growing conditions for the plants. Daily tending of the GreenHab included monitoring temperature and humidity, adjusting fans, watering and measuring amount of water needed, moving and re-potting plants as required, and occasionally harvested mature plants for food. The plants in the GreenHab during the EuroMoonMars-B rotation that required monitoring were avocado, Swiss chard, kale, radishes, watercress, sprouts, broccoli, mint, Viola, basil and Italian mix. The Swiss chard, kale, and

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FIGURE 10. *Swiss chard was grown in the GreenHab, and eventually harvested along with radishes and kale for fresh vegetables that were consumed towards the end of the 2 week rotation. All plants in the GreenHab required daily monitoring for reporting to mission support. Picture courtesy of Jim Urquhart/Reuters.*

radishes were harvested for food, the Italian mix was used as seasoning, and an herbal tea was made. The GreenHab experienced unanticipated maintenance requirements with regards to temperature and ventilation, which required crew time diverted from planned tasks. Failure to attend to the GreenHab would have resulted in a loss of some or all of the plants which, on a real human mission, could lead to mission failure.

The main water pump, which is used to pump water from the outdoor reservoir to the indoor tank, failed and also required unanticipated maintenance. As with the GreenHab, this maintenance diverted crew time from planned activities. In these instances, crew members were pulled from participating in EVAs to assistance in the maintenance. While it is difficult to plan and schedule for unanticipated maintenance, the mission scheduling should be set up to allow for these unforeseen circumstances.

4 Scheduling Outcomes

Overall the mission schedule shows 68 deviations, shown in Figure 11, of the original planning, of which 12 only regard individual crew members. The remaining 56 were affecting the whole crew, e.g. by occurrence of unforeseen issues like a broken pump, which made repair works necessary and shifting of the repair crew's duties to other crew members.

In total 543 actions were planned in the schedule, with the minimum of 29 and the maximum of 60 at one day. For 12 mission days not including transfer days to and from the habitat, this makes an average of 45.25 planned actions per day and 5.7 deviations per day. Also relating the number of deviations to the number of planned actions, 475 actions were conducted as planned, i.e. a ratio of about 87.5 percent. Equipment breakdown, such as the water pump, resulted in 5 deviations that needed immediate attention and could not be implemented in the schedule at a later time as shown in Figure 8. For experiment changes 16 deviations occurred, i.e. experiments or preparation of them took longer than anticipated. For public outreach activities 12 deviations occurred.

Another contributor to the deviations was the time allotted for EVAs. Before the mission the time allotment for EVA preparation has been 30 minutes, assuming being suited up and gathering the equipment for each crew member would not last longer if always an extra crew person was assigned to help with the preparations. The same amount of time had been regarded for post-EVA activities, e.g. storing equipment.

But already with the first EVA it became clear that this time allotment was very optimistic. For 12 EVAs in 8 instances the preparation time has been 1 hour instead, which lead to the fact that during the course of the mission, the later EVAs were planned with 1 hour preparation time in advance. It should be noted that preparation did not involve planning of the EVA, i.e. route selection or scientific considerations, but only the immediate actions before the actual EVA, i.e. packing of equipment (e.g. tools, first aid kit, radio) and suiting up suits for exiting the habitat. Also during two EVAs the initially planned mission time was exceeded and the return to base delayed because sampling took longer than expected.

Other minor causes have been, e.g. deviations regarding data refinement or analysis or changes of daily chores like dinner preparation because other crew members had been finished with their tasks already. It shall be noted that only twice off-time has been scheduled, which was in the evening of the mid-day of the mission and at the last evening. In the former case the off-time was reduced because of repairs necessary.

It can be seen that experiments are the driving factor behind deviations, making up almost one quarter of all schedule deviations. Causes for this have been the collection of more samples than anticipated, more need for sample analysis. It is considered positive that science was the greater contributor to schedule devi-

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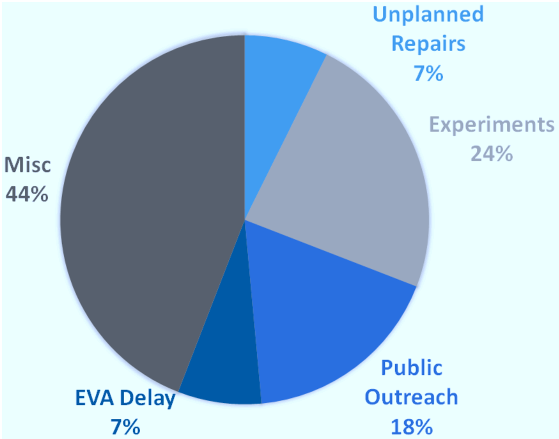

FIGURE 11. *Overview of the 68 deviations to the mission schedule.*

ations as the mission objective of EuroMoonMars-B, and any planetary exploration mission, was scientific return. Unforeseen maintenance issues resulted in some impact in daily planning, however they did not interfere with the overall science objectives. The initial preparation time of 30 minutes anticipated for EVAs has been to small and caused some deviations from schedule (it should be noted that some of these are only noted as one deviation for the EVA block, although several crew members have been affected). Correction of the preparation time allotment to 1 hour however, prevented further deviations from scheduling. Another significant factor has been public outreach. The large number of deviations shows that public outreach was important for EuroMoonMars-B, but not as important as the science for the mission. Especially due to the latter, outreach activities had been postponed a number of times and rescheduled, which explains the large number of deviations.

In general, 87.5% of the scheduled actions during EuroMoonMars-B went according to the time slot they had been given, which is to be considered a success. The planning of the schedule was supported by the need of reporting and discussion, for example the requirement of submitting EVA plans to mission control the day before for approval. Furthermore a conservative assumption on how much time would eventually be needed for a given task, that is incorporating enough time margins, facilitated in maintaining the schedule. At the same time EuroMoonMars-B adherence to the schedule and attempt to conduct the actions as planned in order to facilitate as much gain from the mission as possible was contributing to this high rate of schedule compliance. The fact that each crew member could contribute to the mission scheduling during briefings by giving feedback on the schedule prepared by the commander and executive officer proved to be an efficient method for setting up the daily schedule.

4.1 Operation Outcomes and Recommendations for Future Analogue Campaigns

A previously stated objective to sending humans to conduct field geology, or to explore another planet, is to increase the possible scientific return. However, that increase in return cannot be met by simply adding more tasks to a schedule. Similarly, insufficiently allocating time for each activity or crew rest can result in a degradation in performance or even crew refusal as seen in the 'strike in space' [14]. It is therefore recommended to carefully consider the amount of time allocated to each required task so as to avoid overloads. The schedule adherence during EuroMoonMars-B was considered successful, however the number of deviations did result in tasks requiring completion during previously-scheduled crew rest time.

Daily tasks were classified by function as noted in Section 3; however a priority, or time sensitivity, was not strictly given for each task. It is recommended that tasks be assigned a priority and time sensitivity so that deviations to high priority or time-sensitive tasks can be compensated by altering lower priority or time-insensitive tasks. It is also recommended to have a set of lower priority or time-insensitive tasks available should higher priority tasks conclude quicker than expected.

Future review of mission planning could incorporate several more detailed aspects. For example would it be reasonable to assume that crew morale has an influence on the ability to adhere to the mission schedule. While the subjective view of EuroMoonMars-B is that all crew members have been very motivated not only regarding their only work but also regarding overall mission success, and this may have contributed to the good schedule performance, this cannot be seen as a given fact. Review of other crews' schedule performance could include a parameter of crew moral (e.g. measured by conflicts within the group, or questionnaires) and see if there is a correlation with schedule performance. On the other hand it is likely reasonable to assume that a high rate of schedule deviations can increase the stress on the crew members and therefore actually influence the crew morale nega-

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Problem	Solution	Cost
Insufficient time allocated to EVAs and preparation	Allocate addition time	Loss of time allocated to other duties
Unanticipated maintenance	Assign priority to tasks to account for unanticipated tasks	Potential loss of low-priority tasks
Inefficient text-base communication with Mission Control	Adopt low-bandwidth video messaging	Increased bandwidth consumption
Inefficient use of crew on EVAs	Adopt robotic or automated assistive technologies to off-load tasks	Increased technology development, increased potential for equipment failure
Rapid consumption of desirable food items	Maintain an accurate food inventory, and plan meals accordingly to ensure evenly paced desirable meals	Negligible, other than time spent on inventory
Crew stress	Maintain a pleasant soundscape of sounds of nature in the Hab	Negligible
Crew stress	Allow time for creative outlets, such as music	Negligible, if crew rest time is maintained

Table 4. *Summary of lessons learnt: the encountered problems, the solution to the problem, and the associated cost of the solution*

tively.

One outcome of EuroMoonMars-B has been that the preparation time for EVAs has been about 1 hour. It would be interesting to see if there is a correlation between the preparation time and the purpose of the EVAs. The EVAs of EuroMoonMars-B had been mainly geological purposes and therefore certain parts of equipment needed to be prepared. It is possible that mission with different scientific foci, e.g. technology demonstration, have different experiences. Future investigations could review this further. A higher resolution of tracking the work time of each crew member might allow a thorough assessment on how much time is needed for which action type, i.e. daily routine, administration, maintenance and scientific work.

5 Conclusion

The authors presented the relevant aspects of an analogue test site mission, besides actual scientific activities and discussed their relation on crew well-being, performance and overall mission conduct.

- Sounds of nature and creative outlets can help reduce crew stress
- Effective video communication can replace text-based communication without significant impact on the allowable bandwidth
- Assessment of robotic assistants can lead to improved EVA efficiency
- Crew rest time is usually a buffer for schedule conflicts and is frequently reduced
- Concurrent plan development with daily briefing can help schedule adherence and adapt when necessary

It is recommended to further study these aspects in future missions as they have the potential to greatly influence mission outcome and crew efficiency.

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