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Planning strategies for Mars (analog) missions: real-time, 3-days-in-advance and 1-day-in-advance planning

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The Austrian Space Forum OeWF conducts Mars analog missions with varying location, length and complexity, which include analog astronauts using space suit simulators who conduct a variety of experiments. As well as the scientific and technological benefits gained from these missions, the Flight Plan Team (FPT) focuses on testing different planning strategies for planetary (analog) missions. As the missions tend to involve large numbers of participants worldwide and have high demands regarding experiment time and outcome, they provide a suitable training ground for activity planning and scheduling. Over the course of three missions we applied three different strategies in order to study their overall performance: real-time planning, 3-days-in-advance planning and 1-day-in-advance planning for the OeWF analog missions Dachstein 2012, MARS2013 and World Space Week 2013, respectively. For human planetary missions beyond the Moon, delays in crew-ground communications will rule out real-time planning. The described 1-day and 3-day-in-advance-planning strategies address this difficulty. For robotic missions, decisions in critical circumstances can be postponed and no lives are at risk, whereas human planetary exploration may require short reaction times and cannot await a response. Complete pre-planning is not feasible for manned missions due to their complexity. Additionally, health and safety requirements as well as feedback and interactions, e.g. regarding human-based in-situ decisions on mapping or experiment locations, make complete pre-planning not applicable. Instead, the situation requires detailed advance planning that allows for feedback for mission optimization while giving the astronauts the necessary authority and experiment knowledge to apply autonomous, instantaneous changes to the schedule where necessary. To simulate this situation, an artificial time-delay of 10 minutes in each direction was applied after an initial preparation phase for one of the three analog missions, MARS2013. The remaining two missions have no time-delay. We compare the three planning strategies – real-time, 1-day, 3-days-in-advance – and discuss their implementation together with mission specific advantages and disadvantages: real-time planning allows for instantaneous changes authorized by the Flight Director, but also leads to increased unnecessary changes. These are reduced by advance-planning. Because the request for changes in the activity schedule is restricted to 1 (3) days before, the planning process can be made smoother. However, all crew members have to first adjust to this method. A new challenge with advance planning is that the field crew has to be able to make decisions about changing the activity schedule by themselves. This applies to changes in personnel or activities for health and safety reasons or when equipment is unavailable. The decisions regarding activity changes have to be based on knowledge; this increased level of information has to be carefully prepared. If an experiment cannot be carried out and a replacement has to be determined by the crew, they require knowledge of the region, the requirements and resources and of the priority of the activities planned for the day. By optimizing the planning strategy for analog missions, we prepare an increasingly sophisticated planning strategy for future manned missions to Mars.

I. Introduction

SINCE the beginning of spaceflight, different Mars missions have been planned and launched to advance the understanding of Mars, its origin, its history and its current condition.

Fly-by missions to Mars were the earliest attempts of Mars exploration. The first Mars missions were started in 1960 with the Soviet Mars Program, which remained unsuccessful until 1974 (Mars 5).[1,2] The first successful Mars mission was the US probe Mariner 4; it provided the first close-up photographs around Mars in 1964.[1,2] Mariner 9 was the first spacecraft to successfully enter the orbit around Mars;[3] another milestone was the first landing as part of the US Viking program in 1974.[4] Since then, the geological, biological and climate properties of Mars have been studied from orbit - such as NASA's 2001 *Mars Odyssey*,[5] ESA's *Mars Express* in 2003 and NASA's *Mars Reconnaissance Orbiter* in 2006 - and from the planet itself. Surface experiments have been conducted by rover missions, such as NASA's Mars Pathfinder mission in 1997 and the twin Mars Exploration Rovers Spirit and Opportunity that landed in 2003. Currently the Mars Science Laboratory *Curiosity*, launched in 2011, studies the carbon chemistry, the geology and evidences of water and the past climate, as well as the radiation levels on Mars.[6] However, no crewed mission has been performed yet. For the future it is intended to expand Mars exploration to crewed missions, since curious human explorers bear many potential advantages over pre-programmed robotics.[7] Over the few decades, a number of mission concepts for such an expedition has been proposed; from NASA's 90-Day Report in 1989[8] and the NASA Design Reference Architecture (DRA 5.0) in 2009,[9] to the latest ones proposed by private organizations such as Mars One, The Mars Initiative, or the Inspiration Mars Foundation.

Besides the drastic increase of risks for the astronauts of a crewed mission - e.g. problems arising from zero-gravity, radiation and isolation -, sending astronauts to a planetary body such as Moon or Mars is connected with high mission costs for hardware development and operations. The Apollo Lunar program resulted in a total cost of 152 billion dollars.[10] For missions to Mars, due to the increased complexity and mission duration, estimated costs reach from 30 billion dollars solely for the necessary hardware development[11] up to 450 billion dollars for a complete mission as described in the 90-Day Report.[8,11] Although more recent assessments as the DRA 5.0 using in-situ resource utilization are estimated to be lower in cost,[9] expenses will still exceed robotic missions.[7] Therefore, in order to justify the expenses for sending humans to Mars, the overall mission efficiency and especially the scientific output have to be high, demanding a scientifically efficient use of the mission time.[12] Here, analog missions can play an important role to optimize certain aspects of the mission without the cost of real spaceflight.

II. Analog Planetary Missions

In order to reach an operational Mars mission design, scientists and engineers need to test different strategies in Mars-like environments and artificial laboratories, called Analog Planetary Research (APR). APR sites can be chosen to simulate specific aspects of planetary exploration, e.g. maneuvering in reduced gravity using under-water analog sites or simulating the expected geology of the planet/moon, by choosing desert or cave environments. A non-complete list of existing analog sites that address different (geographical) aspects for simulation purposes is given in Weiss et al.,[13] while the different simulation aspects of previous analog missions are discussed in Deems, E. and Baroff, L.[14] Of interest for Mars analog missions due to their geological properties are sites such as Rio Tinto[15] and the Mars Desert Research Station (MDRS) in Utah.[16,17,18] Other analog missions use remote, secluded sites where human factors and psychological effects can be studied, e.g. the Devon island in Canada,[19] Antarctica,[20] which will especially be of importance for long-distance planetary exploration.[16]

Additionally to the scientific and technological benefits, analog planetary missions provide a test bed for developing and improving planning strategies and mission operations for Mars exploration. A team of planners, the Flight Plan team (FPT) focuses on developing and testing different planning strategies for the planetary (analog) missions of the Austrian Space Forum.

An optimized and appropriate planning strategy can increase the scientific output of a mission and lead to an efficient use of time, budget and personnel.[21] Here, an appropriate planning strategy considers science, operations and crew personnel objectives, including also crew discretionary time, health and safety requirements as well as two-way communications between the crew and the Mission Control Center (MCC).

Over the course of three missions, we applied three different planning strategies in order to study their overall performance: real-time planning, 3-days-in-advance-planning and 1-day-in-advance-planning for the analog missions Dachstein Mars Simulation 2012, MARS2013 and World Space Week Mission 2013, respectively. The aim of this paper is to explain and compare the three planning strategies, and to discuss their implementation listing all their mission specific advantages and disadvantages.

III. The Real-Time Planning Strategy

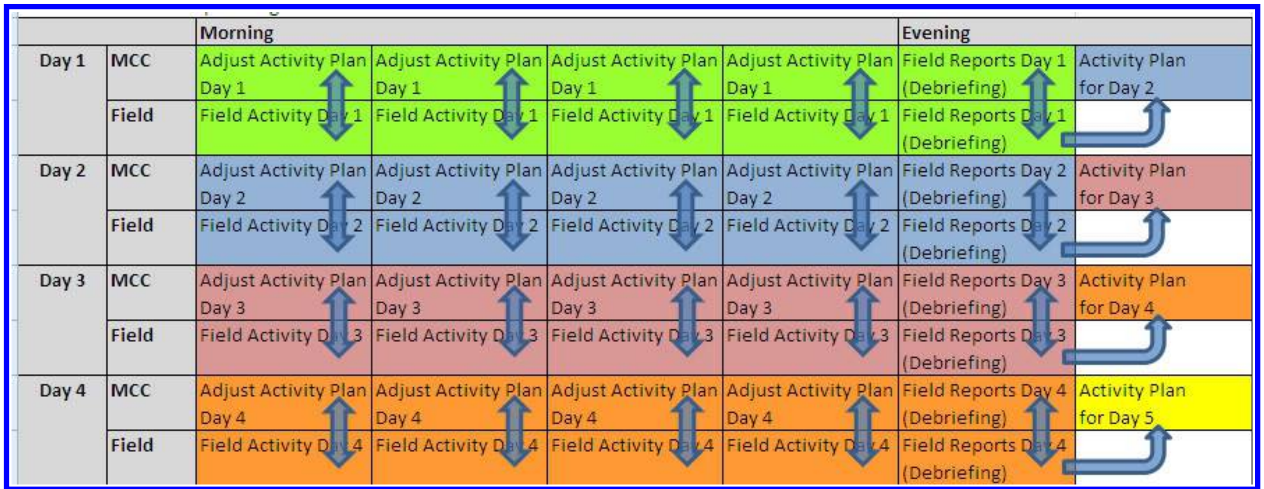
To relieve the astronauts from workload and to increase the scientific efficiency of the exploratory mission, operational tasks not necessarily to be performed on Mars are done remotely in the MCC back on Earth.[12,22] This includes especially the planning of the astronauts' daily activities. Setting up detailed daily schedules and traverse calculations requires sufficient time, resources and an in-depth knowledge of all planned experiments and activities. The plans and schedules are developed by taking into account all available information and are provided to the astronauts on Mars.[12] Vice-versa this requires that the planners at MCC at any time have a detailed overview on the tasks being accomplished by the astronauts, the resources and consumables (e.g. power, fuel, water), the status of all the surface equipment and information on the exploration area.

The MCC provides real-time support and guidance to the astronauts by the means of analyzing and reacting in real-time on new incoming information and unexpected situations instantaneously. The concept of real-time planning was applied for the lunar missions such that the MCC actively guided the astronauts through each step having the ability to interfere if necessary.[22,23] To some extent this strategy can be performed on the International Space Station due to real-time communication, especially for non-standard activities.[24]

For real-time planning, a Mission Plan (MP) is prepared previously to mission start. This MP serves as the basis for the Field Activity Plan (FAP), a more detailed schedule prepared each day of the mission. The FAP includes recent updates and feedback, such as changes in the experiment location, changes of time slots or other requests by Principal Investigators (PIs) for the experiments and instruments. During the mission, the FPT follows the ongoing operations in real-time in the Flight Control Room (FCR) and immediately reacts with shifting and reallocating of time slots on delays and incoming change requests illustrated in figure 1. Therefore, the time schedule is always up to date and accounts for all the latest developments. In the evening of each mission day - after the field operations are finished - the FAP for the next day is created including the latest information. This kind of real-time planning requires a lot of field-MCC interaction during the activities to fine-tune the activity schedule.

This strategy was applied for the Dachstein Mars Simulation 2012, a 5-days mission in the Dachstein Giant Ice Cave in the Austrian Alps.[12] There, teams of 11 countries conducted a total of 12 experiments partly in combination with the Aouda.X Space Suit Simulator developed by the Austrian Space Forum.[12] The short mission duration and the lack of previous experience on planning strategies of the FPT favored the testing of real-time operations. The analog astronaut performing the planned tasks with the Aouda.X possessed a low level of autonomy and was instructed directly by the Capsule Communicator (CapCom) on how to perform these tasks. As changes and delays in the operations became evident, the schedule was adapted immediately by the FPT, also situated in the FCR, and the new instructions were relayed by CapCom. At the same time, PI requests had to be handled, suited and unsuited science operations had to be tracked, the schedules had to be edited accordingly, the developments had to be logged and the new instructions had to be relayed. In some cases, drastic changes to the schedule were made in the MCC on short notice. Unfortunately, these updates could not always be communicated to the analog astronauts and their assistants ahead of time. This led to confusion regarding the upcoming tasks as well as delays due to an increased preparation time. The large number of parallel tasks also became apparent in the workload for the FPT: while before the mission start, the workload was relatively low for the development of the mission plan, it increased drastically during the mission because of the replanning. With the initial amount of staff, the FPT could easily handle pre-mission tasks, but could hardly cope with the workload during the mission. The performance of the mission in regards to suited science activities is given with 41.7% of the 60 planned experiment runs being executed[12] and 41.1% of the total Extravehicular Activity (EVA) time (period between closure and opening of the helmet of the space suit simulator) being used for these, opposed to the planned 74.8%.[21]

Also this method of real-time planning can not be used for future crewed Mars missions, due to the large distances and the respective delay in communications of minimum 4.36 minutes up to a maximum of 20.99 minutes one way.[12] Therefore, the real-time planning strategy can only be used in near-Earth environments, and not for planetary missions further than the Moon, where the delay only made up to 1.28 seconds.[12] This raised the need to develop new and more suitable planning strategies for crewed Mars missions in the future.



		Morning				Evening	
Day 1	MCC	Adjust Activity Plan Day 1	Adjust Activity Plan Day 1	Adjust Activity Plan Day 1	Adjust Activity Plan Day 1	Field Reports Day 1 (Debriefing)	Activity Plan for Day 2
	Field	Field Activity Day 1	Field Activity Day 1	Field Activity Day 1	Field Activity Day 1	Field Reports Day 1 (Debriefing)	
Day 2	MCC	Adjust Activity Plan Day 2	Adjust Activity Plan Day 2	Adjust Activity Plan Day 2	Adjust Activity Plan Day 2	Field Reports Day 2 (Debriefing)	Activity Plan for Day 3
	Field	Field Activity Day 2	Field Activity Day 2	Field Activity Day 2	Field Activity Day 2	Field Reports Day 2 (Debriefing)	
Day 3	MCC	Adjust Activity Plan Day 3	Adjust Activity Plan Day 3	Adjust Activity Plan Day 3	Adjust Activity Plan Day 3	Field Reports Day 3 (Debriefing)	Activity Plan for Day 4
	Field	Field Activity Day 3	Field Activity Day 3	Field Activity Day 3	Field Activity Day 3	Field Reports Day 3 (Debriefing)	
Day 4	MCC	Adjust Activity Plan Day 4	Adjust Activity Plan Day 4	Adjust Activity Plan Day 4	Adjust Activity Plan Day 4	Field Reports Day 4 (Debriefing)	Activity Plan for Day 5
	Field	Field Activity Day 4	Field Activity Day 4	Field Activity Day 4	Field Activity Day 4	Field Reports Day 4 (Debriefing)	

Figure 1. Schematic of the Real-time Planning Strategy. *Before the Mission a Mission Plan (MP) is established to serve as schedule for the first mission day. During this day the occurring changes lead to constant adaptation of the schedule. In the evening the Schedule for the next day is updated integrating the latest information and development. Blue arrows indicate feedback from and instructions to the field.*

IV. The 3-Days-in-Advance-Planning Strategy

The MARS2013 mission was the most advanced crewed analog Mars mission conducted up to now. For the entire month of February, the Field Crew was sent to the desert in Morocco, while a Mission Support Center (MSC) was based in Innsbruck, Austria. To simulate the conditions of a real Mars mission, a ten minute time delay in communication between the MSC and the field crew was introduced.[25] Due to this time delay, the MSC could only support and not control the field crew in real-time, as it was the case during the Dachstein mission, therefore turning the MCC into an MSC.

To meet the demands of such an advanced mission with almost 20 experiments being conducted,[25] a new planning strategy was introduced in February 2013 during MARS2013.[21] The so-called 3-days-in-advance-planning strategy was developed to address the ten minute time delay and to include the lessons learned from real-time-planning. According to Dinkelaker et al.,[26] the completed plan for a day consisted of the Field Activity Plan (FAP) plus additional information (e.g. weather report, traverse maps and procedures). This so-called Daily Activity Package (DAP) was uploaded to the field three days before the target day.[21,26]

The main idea of this planning strategy was to prepare the DAP three days in advance and to only adjust it over the course of the remaining two days until the target day.[21,26] This included no bigger changes but only minor more sophisticated ones. In general, if the DAPs of the two days before the target day were not executed correctly, the DAP for the target day was not changed, instead the changes would impact the planning for the days thereafter.[21] One day before the target day the DAP was approved by the Flight Director and uploaded to the field crew.[26] The different steps and stages involved in the 3-days-in-advance-planning strategy are shown in figure 3. With this strategy, if necessary, the team had more time for implementing urgent re-planning requests due to emergencies.

In reality 62.5% of the DAPs had to be changed more than twice, also during the two days before the target day. 20.8% of the DAPs had to be changed more than 3 times, with the maximum amount of critical changes of the DAP being 8. The two day interval between the planning and the execution of the activities was long enough for critical changes to occur. Critical changes that effected a re-planning included all issues that involved defect hardware or the health of the analog astronauts. In these cases the DAP had to be changed after the official planning (according to the 3-days-in-advanced-planning strategy) finished. The early phase of the mission turned out to be especially problematic: the knowledge that was gained during the first few days regarding the field infrastructure, environment and activities would have improved the planning greatly, but the time it took for the feedback to be implemented delayed such an improvement.

A detailed efficiency analysis of the 3-days-in-advance-planning during MARS2013 can be found in Hettrich et al..[21] During MARS2013, 45.7 % of the total EVA time was used for scientific experiments, during which 75.8% of the planned science goals could be satisfied. However, considering all activities (also suit donning and doffing), only a third of the total time was used for carrying out scientific experiments, although the goal was to be above 50%.

These results led to the idea of introducing another planning strategy for future missions to improve the efficiency. Additionally, the planning strategy had to be adjusted for the upcoming World Space Week (WSW) 2013, which was considerably shorter than MARS2013. This resulted in the 1-day-in-advance-planning strategy.

		Morning				Evening
Day 1	MSC	Deadline for change requests		Activity Plan for Day 4		
	Field	Field Activity Day 1	Field Activity Day 1	Field Activity Day 1	Field Activity Day 1	Field Reports Day 1
Day 2	MSC	Deadline for change requests	Mission Analysis for Day 1	Activity Plan for Day 5	FD Authorisation	
	Field	Field Activity Day 2	Field Activity Day 2	Field Activity Day 2	Field Activity Day 2	Field Reports Day 2
Day 3	MSC	Deadline for change requests	Mission Analysis for Day 2	Activity Plan for Day 6	FD Authorisation	Upload to field
	Field	Field Activity Day 3	Field Activity Day 3	Field Activity Day 3	Field Activity Day 3	Field Reports Day 3
Day 4	MSC	Deadline for change requests	Mission Analysis for Day 3	Activity Plan for Day 7	FD Authorisation	Upload to field
	Field	Field Activity Day 4	Field Activity Day 4	Field Activity Day 4	Field Activity Day 4	Field Reports Day 4

Figure 2. Schematic of the 3-days-in-advance-planning strategy. *Before the Mission a Mission Plan (MP) is established to serve as a rough schedule for the mission activities. The daily tasks for the FPT are to gather the change requests for the day after the target day, then to perform a short mission analysis of the day before and include it together with the feedback from the field crew into the Activity Plan for the target day. This DAP will then get authorized by the Flight Director at T-2 and Uploaded to the field at T-1 day. The color coding symbolizes the associated mile stones. The arrows show the origin for the planning inputs.*

V. The 1-Day-in-Advance-Planning Strategy

The 1-day-in-advance planning strategy was implemented during WSW, which included a 5-day Mars simulation at the Mars Desert Research Station in Utah in October 2013. The 8-hour time difference, the large distance between the MCC and field, and the work with an external field crew brought new challenges for the MCC crew. Since the mission was primarily designed to focus on outreach activities, unlike predecessor missions, there was no artificial time delay introduced to the communication.

The main idea of the method was to plan the daily activities and responsibilities of the crew one day in advance. Specifically, it included half a day of scheduling and traverse planning and half a day of checking and authorizing until the final completion of the DAP. The DAP was then uploaded and sent to the field to all the five MDRS crew members. A schematic of the planning strategy can be found in figure 3, where the different steps during the planning process and the interaction with the crew are shown. The 1-day-in-advance-planning strategy allows for a more prepared EVA in comparison to the real-time planning: the activities should be available to the field crew in advance and the FPT can schedule activities with an updated list of activity priorities/requirements due to mission analysis.

The most particular characteristics of this method are the flexibility and the ability to schedule the FAP and to create the Traverse Plans according to the everyday data and deviations. Flexibility provides the opportunity to the MCC crew to react to unexpected situations and to integrate changes already for the next day. Because this process is a lot faster it becomes a big advantage compared to 3-day-in-advance-planning. The FPT can then reschedule the activities for the next day according to the new information from field crew feedback, as well as mission data analysis. In addition to this, there is also the sufficient time of 24 hours in order to adopt and prepare the schedule of the next day's activities, which is also considered a privilege in comparison with the real-time-planning. Another advantage is the fact that the planning team only needs to concentrate on the next day, unlike the 3-days-in-advance-planning strategy, where the team has to focus on the next three days.

However, the privilege of flexibility could not be fully taken advantage of due to certain circumstances of the mission:

The RSS team requested a certain amount of experiments to be conducted, which the FP team carefully planned. Unfortunately, the information received from the field was sometimes incomplete and there was not always a clear picture of which experiments had been conducted. Additionally, the field crew was not always fully aware of the procedures or the handling of certain experiments.

Especially the incomplete information regarding the conducted experiments led to a confusing situation between the two sides. The FPT inevitably continued planning according to the initial Mission Plan, while the MDRS crew was trying to adjust on its own pace. It should be noted that astronaut autonomy is fully acceptable as part of the 1-day-in-advance-planning, if the astronauts have reasons to deviate from the FAP. These last minute changes and deviations, however, might have consequences that require the planners to adjust the future activity schedule accordingly. Therefore, the MCC crew should definitely be informed about this deviation by the end of the crew's day through their log files and reports. Only a good overview of the accomplished tasks, as well as good communication between the two sides will help to avoid the mistakes by deficient exchange of information. The crew's inexperience with the specific provided planning by the MCC, as well as the whole concept of the WSW on focusing on the outreach events resulted in less data and feedback than initially planned.

With the limited data available, we performed a crude, qualitative analysis. Here, we only considered EVAs taking place in MDRS that were not outreach activities - including outreach activities would have increased the complexity as additional parties were involved.

		Morning				Evening
Day 1	MCC		Deadline for change requests	Activity Plan for Day 2	FD Authorisation	Upload to field
	Field	Field Activity Day 1	Field Activity Day 1	Field Activity Day 1	Field Activity Day 1	Field Reports Day 1
Day 2	MCC	Mission Analysis for Day 1	Deadline for change requests	Activity Plan for Day 3	FD Authorisation	Upload to field
	Field	Field Activity Day 2	Field Activity Day 2	Field Activity Day 2	Field Activity Day 2	Field Reports Day 2
Day 3	MCC	Mission Analysis for Day 2	Deadline for change requests	Activity Plan for Day 4	FD Authorisation	Upload to field
	Field	Field Activity Day 3	Field Activity Day 3	Field Activity Day 3	Field Activity Day 3	Field Reports Day 3
Day 4	MCC	Mission Analysis for Day 3	Deadline for change requests	Activity Plan for Day 5	FD Authorisation	Upload to field
	Field	Field Activity Day 4	Field Activity Day 4	Field Activity Day 4	Field Activity Day 4	Field Reports Day 4

Figure 3. Schematic of the 1-day-in-advance-planning strategy. *Before the Mission a Mission Plan (MP) is established to serve as a rough schedule for the mission activities. The detailed activities are planned one day before the target day and uploaded to the field. Feedback for the crew can be implemented for the following day. Before the scheduling task, a short analysis of the previous day's activities ensures that the recent information can be included in the schedule. The color coding symbolizes the associated mile stones. The arrows show the origin for the planning inputs.*

When comparing executed versus planned activities, we note that most activities (64%) were performed on the day that they were scheduled for (9 out of 14 scheduled activities were performed on the correct day). In most other cases, the astronauts took some liberties regarding the activity schedule. Reasons for changing the activity schedule were amongst others: visitors, other obligations (outreach, getting gas for the ATV), change in personnel (crew members leaving earlier than planned) and change in demands for experiments. Especially changes in personnel tend to be noticed shortly before or even on the target day: sickness or absence due to other obligations can not usually be considered in the advance planning. With a deadline for change requests closer to the target day, these changes can be better accounted for with the 1-day-in-advance-planning strategy than with the 3-days-in-advance-planning strategy. For more thorough analysis there is the need to apply this method to additional missions in the future in order to validate its implementation and efficiency.

VI. Conclusion

Over the course of three different missions, we have applied three different planning strategies: the real-time planning, the 1-day-in-advance planning and 3-days-in-advance planning strategy. There is not solely one planning strategy that is the optimum strategy for all different kinds of missions (optimum in terms of suitability, planning efficiency and achieved science goals), instead it strongly depends on the specific type of mission. Each planning strategy has its own characteristics, advantages and disadvantages that can be compared and weighed against each other. For missions with a time-delay, as will be the case for missions to Mars, advance planning is one likely solution, as opposed to real-time planning where communication is delayed by several minutes. How much in advance we can successfully plan ahead for a mission will also depend on several mission factors, including the complexity and length of the mission, whether it is crewed or uncrewed, the ways of communication between field crew and MCC/MSC and if there is a communication time delay.

The missions discussed in this paper are of different types in terms of complexity, duration, ways of communication and communication time-delay. While the 3-days-in-advance-planning strategy delivered satisfying results for the 28-day mission of Mars2013, it did not seem feasible for the 5-day mission of WSW2013; too much time would pass before feedback of the crew can be implemented and take effect. Adjustments to the environment of the APR site and any unforeseen circumstances of the mission need to be considered in the activity planning a lot faster, because there is less buffer time in the end to make up for changed activities. The advance-planning-period should therefore be a reasonable – i.e. not too large – fraction of the mission duration; for MARS2013 this was 3 days for 28 mission days (ratio of planning days to mission days is 1:9), for WSW2013 it was 1 day for 5 mission days (ratio of 1:5). A shorter mission means that a larger flexibility is required regarding the activity planning so that all scheduled activities can be performed even in unforeseen circumstances.

One way to compare the different planning strategies is to look at the mission outcome and the efficiency of the planning strategy. An efficiency analysis has been performed for MARS2013 and Dachstein 2012; the results are presented in Hettrich et al., 2014 and Hettrich, 2012.[12,21] However, a strong focus on outreach projects during WSW 2013 as well as the short duration of the mission and a crew from outside the OeWF made collecting and comparing the data for this mission more complicated. While previous mission analysis has shown an increase in mission efficiency and overall mission satisfaction for the 3-days-in-advance-planning strategy compared to real-time planning, no such in-depth analysis could be performed for WSW2013. Qualitatively, we note that most of the scheduled activities have been performed on the day they were intended. This implies that the planning strategy was mostly able to take important planning inputs into account on the planning day and avoid drastic re-scheduling on the target day.

We tried to find a way to generalize and compare the three types of planning strategies in addition to the mission efficiency analysis. We summarize the planning strategies' characteristics and rate their applicability to different circumstances in table 1.

The main advantage of real-time planning is its flexibility to react to unforeseen circumstances immediately (see table 1). Additionally, the astronauts do no need to be aware of the overall mission status as they will not be required to make autonomous changes to the FAP. Although the real-time planning strategy proved to be functional (e.g. Dachstein mission), it brings several disadvantages, such as the strain for the FPT. They have to react in real-time continuously, shifting time slots in the schedule during the operations, while only given short amount of time to verify and check the re-planning options.[16] Under time pressure this can lead to errors and not optimal solutions. A DAP that was sent to the field in the morning was quickly outdated due to frequent real-time changes.

A short advance planning period (change request deadline close to the target day, e.g. 1-day-in-advance-planning strategy) does not allow for re-planning on the target day, but it provides the flexibility to implement changes within a short time. It also bears the risk of losing sight of the requirements of individual experiments regarding the set science goals, i.e. the number of runs performed and/or samples over the course of the mission. Thus, by including all change requests coming from MCC/MSC or field crew, the scientific output of the individual experiments can be lowered. To avoid this, it can be useful to create a priority list for the scientific activities, which is based on the science goals stated by the PIs as well as the mission analysis of all previous days. This priority list also helps the astronauts in their autonomous decisions, e.g. when activities have to be reduced due to time or personnel shortcomings.

With a longer advance planning period, as e.g. the 3-days-in-advance-planning strategy, the benefits of a more balanced activity distribution and appropriate EVA time for each of the experiments included in the mission comes with the disadvantage of less flexibility. While a long advance planning period is not suitable for short missions, it allows a more thorough planning with better time management for longer missions. We suspect that the limit are missions shorter than 7 days. During this type of mission it is difficult to set up a schedule with three days of advance planning period and to still be able to conduct all the mission goals, if re-planning will be necessary. During shorter missions, there are fewer days available as a buffer. Therefore, if the goals could not be achieved in the first few days of the mission, it might fail to account for re-planning these goals, making 3-days-in-advance-planning too inflexible for short-term missions.

	Real-time	**3-days-in-advance**	**1-day-in-advance**
Flexibility of the DAP			
ability to react on sudden events	high	low	low
ability to apply changes to the schedule for the same day	high	low	low
implementation speed of feedback to the schedule for upcoming days	high	low	medium/high
quality of rescheduling	low	high	high
Stability of the DAP			
ability to trust in the stability in the DAP at the start of daily activities and to perform it as expected	low	high	high
Activity analysis			
during operations and possibility to implement changes for upcoming days	low	high	high
time for decision-making process	low	high	medium
Awareness of changes to the current DAP			
of the analog astronauts	high	low	low
of the field crew	medium	medium	medium
of MCC/MSC	high	high	high
Suitability for mode of operation			
real-time communication	high	high	high
delayed communication	low	high	high
autonomous decisions of field crew possible	low	high	high
Workload			
for field personnel	medium	medium	medium
for MCC/MSC (planners)	high	low	medium
Application			
short-duration missions (up to 7 days)	high	low	high
long-duration missions (more than 7 days)	medium	high	high/medium

Table 1. Properties of the different planning strategies with respect to certain aspects of a mission.

Even though we can use certain aspects of a mission, such as its duration, to find a more appropriate advance planning period and planning strategy, it might also be useful to consider different phases of a mission: from the MARS2013 mission we know that there is a phase in the beginning of the mission, which can be difficult to plan ahead.[21] The critical point is the interval between planning and execution of activities: changes of circumstances occurred and departures from the FAPs of this interval accumulated. On some days during MARS2013, it could also not be avoided that changes were made just before the target day, which does not support the idea of 3-days-in-advance-planning.

One could consider a more flexible planning strategy for the beginning of the mission, during which feedback leading to changes in the activity planning are very likely. Once the crew in the field and the MCC/MSC are adjusted and activity planning is optimized, a more stable situation is expected. At that point, the planning strategy could be adjusted and the advance planning period increased to plan further ahead.

To be able to optimize the planning strategy in terms of advance planning duration for a specific mission, it would be useful to look at the reasons for changes of the activity plan as well as the time frame in which they occur. This could help to understand where flexibility is needed and where advance planning can be performed with only little adjustments needed. Unfortunately, there is not enough data of the activity plan change requests that include all reasons and timescales to make a detailed, quantitative analysis. Here, a distribution of activity or personnel changes as a function of days before the target day would be useful. It can also be expected that the reasons for changing the activity plan on the target day might be of different nature than the reasons to change an activity plan in advance. This would need to be considered for future analysis.

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References

[1]Robbins, S., " "Journey Through the Galaxy" Mars Program: Mars ~ 1960-1974", SJR Design, 2008, URL: http://jtgnew.sjrdesign.net/exploration_space_planetary_mars.html [cited 22 March 2014].

[2]Mihos, C., "Mars (1960-1974): Mars 1", 2006, URL: http://burro.astr.cwru.edu/stu/advanced/20th_soviet_mars.html [cited 22 March 2014].

[3]O'Gallagher, J.J., Simpson, J.A., "Search for Trapped Electrons and a Magnetic Moment at Mars by Mariner IV", *Science*, Vol. 149 (3689), 1965, pp. 1233-1239.

[4]Bianciardi, G., Miller, J.D., Straat, Patricia A.L., Gilbert, V.L., "Complexity Analysis of the Viking Labeled Release Experiments", *International Journal of Aeronautical and Space Sciences*, Vol. 13, No. 1, 2012, pp. 14-26.

[5]Britt, R.R., "Odyssey Spacecraft Generates New Mars Mysteries", 2003, URL: http://www.space.com/missionlaunches/odyssey_update_030314.html [cited 1 April 2014].

[6]Anderson, A.C., Baker, C.J., Barry, R., Blake, D.F., Conrad, P., Crisp, J., Edgett, K.S., Gellert, R., Gilbert, J., Gómez-Elvira, J., Hassler, D., Litvak, M., Mahaffy, P., Maki, J., Malin, M.C., Mitrofanov, I., Spanovich, N., Vaniman, D., Vasavada, A., Welch, R.V., Wiens, R.C., "Mars Science Laboratory Participating Scientists Program Proposal Information Package", Jet Propulsion Laboratory, 2010, URL: http://earthweb.ess.washington.edu/ess-306/MSL-PIP.pdf [cited 4 April 2014]

[7]Turner, M.J.L., *Expedition Mars*, Springer Praxis Publishing Ltd, London Berlin Heidelberg New York Hong Kong Milan Paris Tokyo, 2004.

[8]Cohen, A., "Report of the 90-Day Study on Human Exploration of the Moon and Mars", 1989, URL: http://history.nasa.gov/90_day_study.pdf [cited 23 March 2014].

[9]Drake, B.G., "Human Exploration of Mars Design Reference Architecture 5.0", NASA/SP–2009–566, 2009.

[10]Larson, W.J., Wertz, J.R., *Space mission analysis and design*, 3rd ed, Microcosm Press & Springer, New York, 1999.

[11]Zubrin, R., *The case for Mars*, edited version 2011, Free Press, New York, 2011.

[12]Hettrich, S., "Human-robotic Mars science operations: itinerary optimisation for surface operations", Master thesis, Institute for Astro-and Particle Physics, University of Innsbruck, Austria, 2012.

[13]Weiss, J., Gardette, B., Chirié, B., Collina-Girard, J., Delauze, H.G., "Simulation and preparation of surface EVA in reduced gravity at the Marseilles Bay subsea analogue sites", *Planetary and Space Science*, Vol.74, 2012, pp. 121-134.

[14]Deems, E., Baroff, L.E., "A Systems Engineering Process for the Development of Analog Missions for the Vision for Space Exploration", *Proceedings of the AIAA Space 2008 Conference*, San Diego, California, September 9-11, 2008.

[15]Orgel, C., Kereszturi, Á., Váczi, T., Groemer, G., Sattler, B., "Scientific results and lessons learned from an integrated crewed Mars exploration simulation at the Rio Tinto Mars analogue site", *Acta Astronautica*, Vol. 94, 2014, pp. 736-748.

[16]Groemer, G.E., Gruber, V., Bishop, S., Peham, D., Wolf, L., Högl, B., "Human performance data in a high workload environment during the simulated Mars expedition "AustroMars"", *Acta Astronautica*, Vol. 66, 2010, pp. 780-787.

[17]Clancey, W., "Participant Observation of a Mars Surface Habitat Mission Simulation", International Journal for Human Support Research, Vol. 11(1/2), 2006, pp. 27-47.

[18]Pletser, V., Foing, B., “European Contribution to Human Aspect Investigations for Future Planetary Habitat Definition Studies: Field Tests at MDRS on Crew Time Utilisation and Habitat Interfaces”, *Microgravity Science and Technology*, Vol. 23, No. 2, 2011, pp. 199-214.

[19]Binsted, K., Kobrick, R.L., Ó Driofa, M., Bishop, S., Lapierre, J., “Human factors research as part of a Mars exploration analogue mission on Devon Island”, *Planetary and Space Science*, Vol. 58, 2010, pp. 994-1006.

[20]Manzey, D., “Human missions to Mars: new psychological challenges and research issues”, *Acta Astronautica*, Vol. 55, 2004, pp. 781-790.

[21]Hettrich S., Dinkelaker, A.N., Sejkora, N., Pfeil, I., Scornet, Q., Moser, L., Boyd, A., Terlevic, R., Luger, U., “Efficiency Analysis of the MARS2013 Planning Strategy”, *Astrobiology*, (submitted for publication).

[22]Bennett, F.V., “Apollo Experience Report - Mission Planning for Lunar Module Descent and Ascent”, *NASA Technical Note,* NASA TN D-6846, 1972.

[23]Kranz, E.F, *Failure is not an option*, Simon & Schuster Paperbacks, New York, 2000, ISBN 978-0-7432-0079-0.

[24]“International Space Station Familiarization - Mission Operations Directorate Space Flight Training Division”, ISS FAM C 21109, TD9702A, Basic Revision, 1998.

[25]Groemer; G.E., Soucek, A., Frischauf, N., Stumptner, W., Ragonig, C., “The MARS2013 Mars Analog Mission”, *Astrobiology*, (submitted for publication).

[26]Dinkelaker, A.N., Hettrich, S., Lupu, E.S., Ghasemzadeh, L., Sekula, A., Alizadeh, A., Frischauf, N., Gołębiowska, I., Groemer, G.E., Jones, N., Kauerhoff, T., Losiak, A., MacArthur, J.L., Moser, L., Pfeil, I., Ragonig, C., Ramirez, B., Scornet, Q., Sejkora, N., Soucek, A., „The mission and activity planning strategy for the MARS2013 mission“, *64th International Astronautical Congress*, Beijing, China, IAC-13-B6,4-V.1, 2013.