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Exploration Mission Tasks: A Technical Manual

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Abridged from: *Generalizable Skills and Knowledge for Exploration Missions (NASA/CR-2018-22045)*
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National Aeronautics and Space Administration
Johnson Space Center Houston, Texas

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EXECUTIVE SUMMARY

This technical manual is an abridgement of the Generalizable Skills and Knowledge for Exploration Missions (NASA/CR-2018-22045) report (Stuster et al., 2019), describing research conducted under Cooperative Agreement 80NSSC18K0042 for the Human Factors and Behavioral Performance Element, Human Research Program, located at the National Aeronautics and Space Administration's (NASA) Johnson Space Center. The research identified tasks that will be conducted by human crew during an expedition to Mars, and the abilities, skills, and knowledge that will be required of crew members.

The 3-year study uses research methods that were developed to analyze the work performed by a variety of civilian and military occupational specialties and is consistent with Human Factors methods. The work began by developing a comprehensive inventory of 1,125 tasks that are likely to be performed during the 12 phases of the first human expeditions to Mars, from launch to landing 30 months later. Sixty subject matter experts (SMEs) rated expedition tasks in terms of (likely) frequency of performance, difficulty to learn, and importance to mission success; a fourth metric (criticality), was derived by summing the mean ratings of the three dimensions. Seventy-two SMEs placed the physical, cognitive, and social abilities necessary to perform the tasks in order of importance for specialist domains identified by the task analysis. The research team then identified: 1) Abilities, skills, and knowledge that can be retained and generalized across tasks and 2) Implications for crew size and composition. Study results also led to recommendations concerning equipment, habitats, and procedures for exploration-class space missions.

Note: The full-mission task inventory was developed during a comprehensive review of documentation and concepts of operations. It was understood by the study team that the tasks were based on currently available information, and that the tools, equipment, propulsion methods, and/or other aspects of actual human expeditions to Mars might be different from those described here, as a consequence of technological development and evolving Mars Design Reference Missions.

The purpose and scope of this technical manual is to present the core, actionable information that resulted from this research. The abridged format is intended to address the needs of development and research teams to quickly access, discern, and use the information in the course of their exploration-related work.

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1.0 INTRODUCTION

Before beginning design and development in any major space program, it is critical to determine the tasks crew members will need to perform to accomplish the mission. This activity is called “Task Analysis” and is part of NASA’s Human-Centered Design process (NASA, 2014). This process includes the identification of crew-performed tasks, as well as important task-related information, which includes: crew roles and responsibilities; task dependencies, duration, and frequency; necessary clothing and equipment; constraints; and knowledge, skills, abilities, and training required to perform the task. The present technical manual summarizes results from a Stuster et al. (2019) study that resulted in a significant step toward more fully characterizing likely tasks during long-duration space missions, skills and abilities needed therein, and the implications of this information. This technical manual is an abridgement of the Generalizable Skills and Knowledge for Exploration Missions (NASA/CR-2018-22045) report describing research conducted under Cooperative Agreement 80NSSC18K0042 for the Human Factors and Behavioral Performance Element, Human Research Program, located at the NASA Johnson Space Center.

Long-duration missions pose new and more serious hazards to crew, including increased feelings of isolation and confinement, and greater distance from Earth, leading to potential communication delays and blackouts. These more hazardous working conditions necessitate a greater clarity for the tasks being undertaken, which was the focus of the original study. This technical manual is intended to be used by Exploration mission development and research teams who need to have an understanding of the mission tasks crew will likely be performing during future deep space missions (e.g., Mars). Complete results and detailed information about the study can be found in the original publication (Stuster, 2019).

2.0 METHOD

This study began with an extensive background literature review of documents related to long-duration Mars mission planning. This review, along with interviews with mission planners and astronauts, served as the foundation for the identification of a variety of expedition tasks across phases of a Mars mission.

In order to assess expected tasks and abilities on a long-duration Mars mission, the Critical Abilities and Tasks (CAT) method was utilized to create an exhaustive list of likely tasks to be performed during a long-duration Mars mission. The following activities were performed as part of the CAT method.

2.1 Task List Development

A comprehensive inventory of actual and expected tasks was developed, with each task statement phrased as: (action verb + object + how task is performed + reason for the action). For example: *Inspect circuit board visually to detect evidence of electrical short*. A total of 1,125 tasks were created in this process, and were subsequently categorized and summarized into 158 representative summary task statements (see Appendix A).

2.2 Task Ratings

Sixty SMEs, including astronauts, flight controllers, flight surgeons, engineers, biologists, geologists, psychologists, physiologists, and human factors specialists, were asked to use a five-point Likert scale to rate the following questions with respect to the 158 summary task statements: 1) *How frequently is the task performed?* 2) *How difficult is it to learn how to perform the task?* and 3) *How important is the task to mission success?*

2.3 Crew Specialty Definition

The full list of 1,125 task statements was used to identify task functions for each task statement (e.g. Piloting, Construction, and Geology). From these task functions, eight primary crew specialties were defined by the researchers: leader, biologist, geologist, physician, electrician, pilot/navigator, mechanic/engineer, and computer specialist. Seventy-two SMEs from these specialty areas were recruited to participate in an abilities card sorting task.

2.4 Abilities Card Sorting

A list of 58 physical, cognitive, and social abilities was developed based on the Fleischman 1967 taxonomy of human performance, plus six additional abilities. A card-sort exercise was completed by 72 SMEs from the identified crew specialty areas. Fifty-eight individual physical cards, representing relevant crew abilities, were placed in order of importance toward mission success for their respective crew specialty. Cards were initially sorted into three categories (More Important, Important, and Less Important), and then put in sequential order of importance within each category.

3.1 RESULTS

3.1 Task Analysis

Tables 1-3 below show the top 10 summary task statements for SME ratings of: Frequency, Difficulty to Learn, and Importance. Mean scores for the three questions about each summary task statement were combined to compute a metric, labeled "Computed Criticality," shown in Table 4. Some tasks might be frequently performed, but easy to learn or relatively unimportant to mission success. Other tasks might be infrequently performed, but difficult to learn or very important to mission success.

3.1.1 Frequency

Table 1 shows the top 10 summary task statements based on SME ratings of frequency, with row number 1 being most frequent. The top 10 high-frequency tasks come from the communication, exercise, and habitability function categories.

Table 1. Top 10 Summary Task Statements Ordered by **(Likely) Frequency**

	Function	**Summary Task Statement**
1	**Comms**	Interact/communicate with other crew members directly during Mars Surface Operations (MSO).
2	**Exercise**	Exercise daily using onboard equipment during Cruise to Mars (CTM).
3	**Habitability**	Prepare/eat meal, manually, using interplanetary space vehicle food hydration/heating equipment/galley during Cruise to Earth (CTE).
4	**Habitability**	Prepare and consume meals in surface habitat during MSO.
5	**Exercise**	Exercise daily using onboard equipment during Cruise to Earth.
6	**Habitability**	Sleep for approximately 8 hours each 24-hour period during CTE.
7	**Habitability**	Prepare/eat meal, manually, using interplanetary space vehicle food hydration/heating equipment/galley during Cruise to Mars.
8	**Habitability**	Sleep for approximately 8 hours each 24-hour period during MSO.
9	**Habitability**	Use interplanetary space vehicle waste management systems for liquid/solid waste (i.e., toilet/bodily function) during Cruise to Earth.
10	**Habitability**	Use interplanetary space vehicle waste management systems for liquid/solid waste (i.e., toilet/bodily function) during Cruise to Mars.

3.1.2 Difficulty to Learn

Table 2 shows the top 10 summary task statements based on SME ratings of difficulty to learn, with row number 1 being most frequent. The top 10 difficult-to-learn tasks come from the medical extravehicular activity (EVA) and piloting function categories.

Table 2. Top 10 Summary Task Statements Ordered by **Difficulty to Learn**

	Function	Summary Task Statement
1	**Medical**	Respond to medical emergencies, following procedures and with equipment provided, during Cruise to Mars (CTM).
2	**EVA**	Conduct Extra-Vehicular Activity (EVA) to perform maintenance or retrieve items from outside the interplanetary space vehicle during Cruise to Mars.
3	**Piloting**	Perform piloting functions during Mars Surface Descent.
4	**Medical**	Respond to medical emergencies, following procedures and with equipment provided, during Cruise to Earth.
5	**Piloting**	Perform piloting functions during Earth Descent.
6	**Medical**	Respond to medical emergencies, following procedures and with equipment provided, during Mars Surface Operations (MSO).
7	**Piloting**	Perform piloting functions during Mars Orbit Injection.
8	**Piloting**	Perform piloting functions during Mars Orbit operations
9	**EVA**	Conduct EVA to perform maintenance or retrieve items from outside the interplanetary space vehicle during Cruise to Earth.
10	**Piloting**	Monitor systems and perform piloting functions during Mars Surface Ascent.

3.1.3 Importance

Table 3 below shows the top 10 summary task statements based on SME ratings of importance of (correct) task performance to mission success, with row number 1 being most frequent. The top 10 important tasks come from the technical, piloting, and medical function categories.

Table 3. Top 10 Summary Task Statements Ordered by **Importance**

	Function	**Summary Task Statement**
1	**Technical**	Respond to technical emergencies, following procedures and with equipment provided, during Cruise to Mars.
2	**Piloting**	Perform piloting functions during Mars Orbit Injection.
3	**Technical**	Perform emergency functions in surface habitat or modules during MSO.
4	**Medical**	Respond to medical emergencies, following procedures/with equipment provided, during Mars Surface Operations.
5	**Piloting**	Perform piloting functions during Mars Surface Descent.
6	**Technical**	Respond to technical emergencies, following procedures and with equipment provided, during Cruise to Earth.
7	**Piloting**	Monitor systems/perform piloting functions during Mars Surface Ascent.
8	**Piloting**	Perform piloting functions during Earth Approach.
9	**Piloting**	Perform piloting functions during Earth Descent.
10	**Technical**	Prepare for Mars Surface Ascent during Mars Surface Operations.

3.1.4 Computed Criticality

The top 20 percent (32 statements) of the 158 summary task statements are listed in the following table ordered by the computed measure "Criticality" (sum of Frequency, Difficulty, Importance), with the most critical tasks being listed at the top. For example, line 1 ('Science EVA: Perform science-related EVA functions during Mars Surface Operations (MSO).') is in bold with the highest criticality value of "12." The mean values for Frequency, Difficulty to Learn, and Importance are listed for each statement. The top summary task statement in each dimension is shown in bold. For example, the highest mean value for 'Frequency' is 'Comms: Interact/communicate with crew members directly during MSO,' with a Frequency rating of 4.6.

Table 4. Top 20 Percent Summary Task Statements Ordered by **Computed Criticality**

		Summary Task Statement	Criticality	Frequency	Difficulty	Importance
1	**Science EVA**	**Perform science-related EVA functions during MSO.**	**12**	3.7	4	4.3
2	Piloting	Monitor systems/perform piloting functions during Mars Surface Ascent.	11.9	2.9	4.2	4.8
3	Piloting	Perform piloting functions during Mars Surface Descent.	11.8	2.6	4.4	4.8
4	**Comms**	**Interact/communicate with crew members directly during MSO.**	11.6	**4.6**	2.3	4.7
5	Piloting	Perform piloting functions during Earth Descent.	11.6	2.5	4.3	4.8
6	Piloting	Perform piloting functions during Mars Orbit Injection.	11.5	2.4	4.2	4.9
7	Piloting	Perform piloting functions during Mars Orbit operations.	11.5	2.6	4.2	4.7
8	Piloting	Enter control inputs, manually/visually with gloved hand, to pilot Earth Ascent Vehicle (EAV) during launch and cruise to LEO/CLO.	11.5	2.8	4	4.7
9	Piloting	Monitor systems/perform piloting functions during Trans Earth Injection.	11.4	2.8	3.9	4.7
10	Piloting	Perform piloting functions during Earth Approach.	11.4	2.5	4.1	4.8
11	Piloting	Assess displayed information, cognitively, to determine readiness to launch to LEO/CLO.	11.3	3.1	3.6	4.6
12	EVA	Conduct Extra-Vehicular Activity (EVA) to perform maintenance or retrieve items from outside the interplanetary space vehicle during Cruise to Mars.	11.3	2.2	4.5	4.6
13	Monitoring	Monitor displays/verify configurations before/during launch to LEO/CLO.	11.3	3.6	3.3	4.4
14	Monitoring	Monitor systems during Earth Descent.	11.3	3.5	3.4	4.4

		Summary Task Statement	Criticality	Frequency	Difficulty	Importance
15	Monitoring	Perform monitoring functions in surface habitat or modules to ensure crew and system health during Mars Surface Operations.	11.3	3.9	3	4.4
16	EVA	Enter/exit surface habitat, manually, while wearing pressure suit and helmet, during Mars Surface Operations.	11.3	3.5	3.3	4.5
17	Medical	Perform medical diagnoses and evaluations, cognitively, during MSO.	11.3	2.7	4.1	4.5
18	Robotics	Perform robot operations-related functions during MSO.	11.3	3.5	3.8	4
19	Science	Perform geology-related science functions in surface habitat or modules during Mars Surface Operations.	11.2	3.5	3.8	4
20	Piloting	Assess displayed information, cognitively, to determine readiness for TMI.	11.2	3	3.6	4.6
21	Medical	Monitor crew behavioral health/respond to behavioral health issues during Mars Surface Operations.	11.2	3.1	3.6	4.5
22	Monitoring	Monitor systems to ensure proper functioning during Cruise to Mars.	11.2	3.9	3	4.3
23	Medical	Perform medical diagnoses/evaluations, cognitively, during Cruise to Mars.	11.2	2.6	4.1	4.5
24	**Medical**	**Respond to medical emergencies, following procedures and with equipment provided, during Cruise to Mars.**	11.2	1.8	**4.5**	4.7
25	Piloting	Perform surface rover piloting/driving functions during MSO.	11.2	3.5	3.4	4.3
26	Medical	Respond to medical emergencies, following procedures and with equipment provided, during Mars Surface Operations.	11.2	2.1	4.3	4.8
27	EVA	Perform surface EVA physical functions on foot during MSO.	11.1	3.3	3.5	4.4
28	Piloting	Adjust system controls, manually during buffeted descent, in response to displayed information.	11.1	2.7	3.9	4.6
29	**Technical**	**Respond to technical emergencies, following procedures and with equipment provided, during Cruise to Mars.**	11.1	2.1	4.1	**4.9**

		Summary Task Statement	Criticality	Frequency	Difficulty	Importance
30	Piloting	Monitor systems during Mars Surface Descent.	11.1	3.1	3.5	4.5
31	Medical	Perform tests and examinations, physically, to support medical diagnoses during Mars Surface Operations.	11.1	2.7	3.9	4.5
32	Science	Perform biology-related science functions in surface habitat or modules during Mars Surface Operations.	11.1	3.5	3.6	4

What is it about the surface science-related EVA tasks that elevated that summary statement to the top of the Computed Criticality list? The next EVA-related summary task is 12th on the list, *Conduct Extra-Vehicular Activity (EVA) to perform maintenance or retrieve items from outside the interplanetary space vehicle during Cruise to Mars*. This task was estimated to be performed very infrequently, if at all, during the cruise to Mars, and would be in response to a major equipment malfunction. EVAs in space are always difficult and dangerous and are performed only if important to the mission.

A review of the EVA-related summary statements, the component tasks, and their relative orders reveals that the factors that contributed to elevating science-related EVA tasks to the top of the Computed Criticality list are: 1) Science, the reason for going to Mars; and, 2) EVA, which is difficult to perform, dangerous, and only done for important reasons. Similar analyses were conducted to identify contributing factors to other high computed criticality scores. For example, summary task statements concerning piloting received high scores for Importance; medical tasks were rated high on Difficulty to Learn; and monitoring tasks were elevated by high scores for likely Frequency.

3.2 Results of the Ability Ranking

A total of 72 SMEs, representing the technical specialties identified during the task analysis, performed the ability card-sort for their respective roles; six SMEs ranked the abilities for more than one technical specialty, and 42 of the SMEs also ranked the abilities for the role of expedition leader. A list of the abilities used in the activity can be found in the full report. The eight crew specialties/roles include leader, biologist, geologist, physician, electrician, pilot/navigator, mechanic/engineer, and computer specialist.

Nine lists are shown in Table 5, one for each of the eight crew specialties, and one based on all ability rankings. These lists were derived by calculating the mean rankings of abilities for each crew specialty/role. Means and standard deviation values for these and additional ability rankings can be found in the full report. Analysis focuses on the top 10 abilities for each of the specialties (i.e., the abilities above the highlighted row in each table). Numbers of SMEs and numbers of abilities in the More Important category for each list are in parentheses. Note that 6 out of the 72 SMEs represented and ranked multiple specialty area abilities; in addition, although all SMEs were invited to rank the leader abilities, only 42 elected to do so.

Table 5. Top 10 Most Important Abilities by Specialty in Descending Order of Importance

	Leader (n=42)
1	Teamwork
2	Confidence
3	Problem Sensitivity
4	Patience
5	Emotional Control
6	Oral Expression
7	Tolerance
8	Inductive Reasoning
9	Speech Clarity
10	Deductive Reasoning

	Pilot/Navigator (n=10)
1	Reaction Time
2	Control Precision
3	Spatial Orientation
4	Rate Control
5	Time Sharing
6	Confidence
7	Emotional Control
8	Response Orientation
9	Teamwork
10	Speed of Closure

	Physician (n=11)
1	Problem Sensitivity
2	Inductive Reasoning
3	Deductive Reasoning
4	Confidence
5	Patience
6	Speed of Closure
7	Teamwork
8	Oral Comprehension
9	Manual Dexterity
10	Finger Dexterity

	Biologist (n=12)
1	Inductive Reasoning
2	Confidence
3	Deductive Reasoning
4	Information Ordering
5	Patience
6	Selective Attention
7	Problem Sensitivity
8	Arm-Hand Steadiness
9	Finger Dexterity
10	Originality

	Geologist (n=15)
1	Inductive Reasoning
2	Deductive Reasoning
3	Teamwork
4	Patience
5	Confidence
6	Spatial Orientation
7	Originality
8	Oral Expression
9	Selective Attention
10	Visualization

	Computer Specialist (n=10)
1	Inductive Reasoning
2	Deductive Reasoning
3	Problem Sensitivity
4	Information Ordering
5	Mathematical Reasoning
6	Written Comprehension
7	Oral Comprehension
8	Time Sharing
9	Oral Expression
10	Confidence

	Mechanic/Engineer (n=10)
1	Inductive Reasoning
2	Problem Sensitivity
3	Deductive Reasoning
4	Manual Dexterity
5	Patience
6	Written Comprehension
7	Originality
8	Visualization
9	Mathematical Reasoning
10	Teamwork

	Electrician (n=11)
1	Inductive Reasoning
2	Problem Sensitivity
3	Confidence
4	Deductive Reasoning
5	Information Ordering
6	Visual Color Discrimination
7	Finger Dexterity
8	Manual Dexterity
9	Originality
10	Selective Attention

	All Specialties Combined
1	Inductive Reasoning
2	Deductive Reasoning
3	Problem Sensitivity
4	Confidence
5	Patience
6	Teamwork
7	Information Ordering
8	Originality
9	Speed of Closure
10	Selective Attention

The results of the task-rating and ability-ranking, presented here, were used by the study team to identify social skills and cognitive and physical abilities necessary for eight crew specialty/roles during scientific expeditions to Mars. The next step was to identify the abilities and skills that are common to multiple crew roles, which will enable development of recommendations for optimizing personnel-selection and cross-training. The goal of the process is to identify strategies that will allow the fewest number of crew members to perform the expected work safely, and to be prepared to perform other, less-likely tasks, if necessary. Those considerations are addressed in the following section of this report.

3.3 Personnel Selection and Crew Composition

Analyses indicate that the work encompassed by the 1,125 tasks identified during the study could be performed by the eight primary crew specialties/roles listed below, with four ancillary roles. The following section addresses personnel-selection and cross-training strategies with the goal of providing these key competencies and backups with the fewest number of crew members.

Primary Crew Roles		Ancillary Crew Roles
Leader	Mechanic	Crew Medical Officer (CMO)
Biologist	Electrician	Botanist
Geologist	Pilot/Navigator	Astrophysicist
Physician	Computer Specialist	Equipment Operator

It was assumed that the personnel-selection process for an expedition to Mars will probably not allow the recruitment of eminent specialists, but rather, individuals will be drawn from existing cadres of space-qualified personnel, almost certainly representing international partners. The research team identified a four-person hypothetical crew composition, shown below, by a rational process based on results of the task analysis and ability rankings to illustrate a potential assembly of crew to satisfy operational requirements. For additional five- and six-person potential crew configurations, see the original unabridged report.

Four-Person Crew

Primary Specialty/Roles	Backup Responsibilities
Pilot/Navigator/Leader/Astrophysicist	Geologist/Computer Specialist/CMO
Physician/Computer Specialist	Biologist/Mechanic/Electrician/Botanist
Mechanic/Electrician/Equipment Operator	Pilot/Navigator/Astrophysicist/CMO
Geologist/Biologist/Botanist	Equipment Operator/Leader/CMO

4.0 STUDY IMPLICATIONS

Results of the task analysis were reviewed to identify descriptions of the expected work that have clear design implications. Many of the implications identified during the review will become apparent to engineers when they begin designing spacecraft and equipment for the first expeditions to Mars. The most salient design implications are listed below as part of a systematic approach to task analysis. Implications are presented in seven categories: science, egress the Mars descent vehicle, medical, habitability, safety, reliability, and crew selection/training.

4.1 Science

The primary purpose of sending humans to Mars is to conduct science. *Perform science-related EVA functions during Mars Surface Operations* was the summary task statement rated highest overall by the SMEs in the computed criticality measure.

Together, the eight science-related summary task statements comprise a total of 121 tasks in the fields of biology, geology, and human research. Science-related tasks represent 11 percent of the total task inventory and 20 percent of the tasks listed for MSO. Most of the science-related tasks will require equipment to perform and have clear design implications. A few examples are listed below; however, designers must eventually address the specific equipment requirements of every task.

Example Science-Related Tasks	Design Implications
Retrieve geological tools and equipment from storage and carry to surface rover/trailer, manually while wearing surface EVA suit, to prepare for reconnaissance.	Lightweight tools optimized for use with gloved hands; rover trailer.
Collect geological samples, manually using hand auger, while wearing surface EVA suit.	Specialized tools with safety features to prevent suit punctures.
Inspect geologic samples, visually using hand-held magnifying tool/microscope while wearing surface EVA suit in the field, to conduct preliminary analysis.	Magnifying tool that can be used while wearing surface EVA suit.
Record field notes, verbally while wearing surface EVA suit, to preserve observations for later transcription.	Audio and video recording capability in surface EVA suit.
Scan distant planetary surface, visually through clear visor, to identify potential sites for geological research and collection.	Clear helmet visor to permit seeing contrasting color of strata/rocks.
Deploy and operate ice core drilling tool, manually while wearing surface EVA suit, to obtain ice core sample for analysis.	Easily transported equipment for operation with gloved hands.
Operate rotary/percussion drill to depth of 10 meters with assistance of one other crew member while wearing surface EVA suit.	Drilling equipment for operation by two with safety features.
Examine sedimentary core sample, using aseptic device/procedures while wearing surface EVA suit, to identify if sample contains biologic or toxic elements.	Science module for geological and biological research with aseptic capability.
Compose/update log of samples, using keyboard in surface habitat/laboratory, to create inventory of material collected to date.	Computer/software for inventory of samples collected.
Conduct wet chemistry experiment, manually in laboratory module while wearing protective garments, to test sample material for biological content.	Science module for geo/bio research; special equipment and instruments, glovebox.

4.2 Egress the Mars Descent Vehicle (MDV)

Astronauts are extremely weak when they return from 6 months on the International Space Station (ISS), despite having exercised vigorously for more than 2 hours each day to maintain cardiovascular conditioning, muscle mass, and bone density. They must be helped out of their capsules by ground personnel and placed in reclining chairs before being carried to a waiting helicopter.

One veteran astronaut has identified two concerns: 1) The immediate response to landing, which includes dizziness, headache, pallor, sweating, nausea, and sometimes vomiting; and, 2) Prolonged effects, which include, locomotion and coordination problems, neuro-vestibular disturbances, orthostatic intolerance, and reduced muscle and bone strength. The intensity of both immediate and prolonged effects is generally proportional to the time spent in the absence of gravity, but responses vary. Some astronauts recover quickly, while others require weeks, and that is with assistance provided by ground personnel. Some of the effects might be mitigated by the lower gravity on Mars (i.e., 38 percent of Earth's gravity); that is, astronauts will not feel quite as "heavy" as they feel when they return to Earth; however, they almost certainly will experience the other negative effects, especially neuro-vestibular-induced nausea. And, there will be no one waiting on the surface to help the first explorers of Mars egress their MDV and then carry them to their habitat.

Design Reference Architecture (DRA)-5 included a Mars lander sufficiently large to accommodate the crew for up to 30 days while they adapted to the planet's gravity. It was assumed, as a worst-case scenario, that the descent vehicle would be as small as possible (to minimize mass/propellant requirements); that is, the MDV would be suitable only for transporting the crew from their interplanetary ship in orbit to the surface of Mars. The MDV would lack the volume and habitability features that might enable the crew to remain in it until they adapt to Martian gravity (i.e., the crew would be arranged elbow-to-elbow like EVA-suited sardines). Either a more massive MDV must be used, one that is capable of transporting the crew to the surface and supporting them for a week or two until they adapt, or other provisions must be provided to enable egress. In this worst-case scenario, special hand-holds and a device for lowering crew members from the MDV's hatch to the surface (rather than a ladder) would be needed, as would a device, perhaps resembling a "walker," to assist weakened crew members to transition from the MDV to their nearby surface habitat after landing. It also would be helpful to direct the pre-positioned surface rovers remotely to retrieve the crew members at the landing site and then transport them to the habitat. These design features might be required even if the crew lands in a larger, DRA-5-type MDV and is allowed time to adapt before egressing.

4.3 Medical

Medical tasks are the most numerous of the occupational categories and are among the most difficult to learn and important to mission success. Although many of the medical tasks, such as *Perform surgery, manually using available instruments, to repair a detached retina*, are unlikely, the expedition physician must be prepared with the knowledge, decision-aids, and instruments to perform them. Other medical tasks, such as *Perform surgery, manually using available instruments, to repair a compound fracture of arm or leg bone*, are more likely during an expedition to Mars. The incidence of serious physical injury during a conjunction-class mission was estimated, based on Antarctic experience, to be between four and 12 cases among a crew of six, with the most-likely injuries to occur during surface operations and to involve trauma to the hands and feet (Stuster, 2010). Task analysis results and analog experience indicate the need for robust medical capabilities to diagnose and treat physical injuries during an expedition to Mars.

Medical data from Antarctic stations also were used in the study mentioned previously to estimate the probability of behavioral problems occurring during an expedition to Mars (with "serious problem" defined as requiring at least brief hospitalization if on Earth). The estimates ranged from 0.37 to 0.89 cases among a crew of six during a 905-day conjunction-class expedition; the higher estimates are direct extrapolations from Antarctic experience, whereas the lower estimates reflect adjustments for the comparatively rigorous screening and selection of space crews. These predictions based on analog data suggest that methods will be needed to help individual crew members resolve behavioral issues during their 30 months of living and working together in isolation and confinement. A promising candidate solution for this requirement is the Virtual Space Station (Anderson, Fellows, Binsted, Hegel, & Buckey, 2016). The Virtual Space Station is a self-guided, multimedia program that addresses psychosocial problems, including depression, interpersonal conflict, and anxiety (Anderson et al., 2016). The software has been tested successfully in space-analog environments and could be used as part of pre-mission training and for crew members to receive assistance confidentially during an exploration-class space mission.

4.4 Habitability

Habitability includes the features of a built environment that affect human performance and adjustment. More than 100 habitability tasks are included in the created Mars task lists and they were rated by the SMEs to be among the most-frequent tasks to be performed (e.g., preparing and eating meals, sleeping). Humans can endure austere conditions if they must; however, optimum performance is facilitated by habitability features such as, 1) variety and self-selection of food items; 2) a wardroom or galley that enables the crew members to eat meals together; 3) recreation and leisure materials and equipment; and, 4) private sleep quarters. Designers should consider the provision of habitability features, such as these, to be analogous to overbuilding, a standard method used by engineers to ensure reliability of physical systems (e.g., designing a valve to withstand twice the pressure expected during operation).

Interplanetary ships and surface habitats must provide areas sufficiently large to allow entire crew members to eat meals together and to meet for planning activities. Eating together mitigates sub-group formation and fosters both interpersonal communication and group solidarity. Meeting together for administrative and planning functions is a physical requirement of task performance.

Living in close proximity to other humans can become stressful. For this reason, everyone who lives and works in an isolated and confined environment for a prolonged period seeks time away from crewmates. The private sleep chambers onboard the ISS help satisfy this requirement for astronauts and cosmonauts. Facilities such as the private sleep chambers provided for ISS crew will be required on interplanetary ships and in surface habitats.

Half of the top 20 percent of most-frequent summary task statements are habitability tasks: Preparing and eating meals, sleeping, and using hygiene facilities. Six of the most frequent summary statements describe communications among the crew and three are exercise-related tasks. None of the most-frequent tasks was rated among the most difficult to learn and only one made it to the most-important list (i.e., sleep during CTM). Designers might be tempted to devote less attention to the equipment needed for tasks that are easy to learn or relatively unimportant, compared to equipment used to perform critical tasks. However, frequently performed tasks expose users to the risks of inadequate design (errors, inadvertent acts, frustration) as frequent driving exposes motorists to greater risk of crashing. In other words, sleep chambers, food and hygiene systems, and exercise and communication equipment intended for interplanetary ships and surface habitats must be designed with the same attention to usability as the controls and displays that will be used to pilot a spacecraft during contingencies and to respond to technical emergencies.

4.5 Safety

Monitoring systems and responding to alarms were rated by the SMEs among the most important tasks to be performed during a Mars expedition; responding to technical emergencies during the CTM was rated by the SMEs as the most-important of the 158 summary statements; responding to technical emergencies was 3rd overall during MSO and 6th overall during the CTE. The greatest threats to the safety of space crews that might be announced by an alarm are: 1) fire; 2) hull puncture followed by rapid decompression; 3) outgassing, primarily an ammonia leak; and, 4) solar particle events. All four of the threats have occurred on the ISS, but none with catastrophic consequences, due largely to vigilance, training, sensitive detectors, and automatic alarms. The cost of protection by effective sensor systems is frequent false alarms, which are a source of annoyance to ISS crew. Responding to false alarms interrupts work during the "day" and sleep at "night"; however, complaints about false alarms are minimal because everyone knows that a fire, hull breech, or ammonia leak could be fatal. An astronaut wrote in his journal, "Another smoke detector alarm today. I was exercising but made sure I checked out the situation. It is good training to react as if it is a real emergency" (Stuster, 2016). A few safety-related design implications of task analysis results are listed, below.

- Resist the temptation to disable audible alarms.
- Provide easy access to fire extinguishers in spacecraft and in surface habitats/rovers.
- Provide tethers for connecting crew members together during EVAs over uneven terrain or during dust events.
- Provide ready access to tools and equipment needed to detect and repair hull breeches in spacecraft and in surface habitats.
- Provide an automatic (self-sealing) capability to repair punctures of surface EVA suits, with ready access to materials to make permanent repairs manually in the field.
- Provide shielded areas in the interplanetary ship and in surface habitats to protect crew from solar particle events (e.g., surround sleep chambers with water storage or thick plastic panels; cover surface habitats with regolith).
- Provide a dust removal capability at the entrance to surface habitats to prevent contamination of the interior; a portable method also will be needed to remove dust from suits and boots before entering rovers and the Mars Ascent Vehicle.

4.6 Reliability

A 3-year expedition to Mars will test the endurance of both humans and their technology. Approximately 10 percent of the 1,125 tasks the crew of a Mars expedition must be prepared to perform involve maintenance and repair, from the spacecraft to the software that will control all systems. Ensuring the reliability of technological components of the enterprise would reduce maintenance workloads and overall risk; it also would increase crew confidence in systems and the probability of mission success. Engineers use four basic design strategies for increasing reliability and reducing the risk and effects of component or system failure:

- *Redundancy.* Having two spares for every item needed provides protection against an undetected flaw in a primary item and unexpected damage to the replacement. Triple redundancy has been favored by NASA since the Mercury Program and was a primary strategy of previous explorers.
- *Overbuilding.* Engineers typically design a structure or system component to withstand more than the maximum stress, load, or pressure that is expected. A 150 percent design rule increases the cost of a retaining wall and the weight of a rocket motor; however, the strategy also increases the probability that neither item will fail catastrophically.
- *Graceful degradation.* Sudden, catastrophic failure can overwhelm intrinsic precautions and cause a cascade of unexpected negative consequences. Systems should be designed to degrade gradually to allow sufficient time for isolation, replacement, or repair.
- *Maintainability.* Systems intended for use in remote environments should be designed to enable repair by human operators and tenders. This strategy includes provisions for accessibility, spare parts, appropriate tools, and procedures and schematics to guide the processes.

All four of the strategies described here should be employed to increase the reliability of mechanical, electrical, and software components of exploration-class space missions.

4.7 Crew Selection and Training

Additional implications of the task analysis (and results of other research) to crew selection and training are:

- Provide training in Mars geology to all crew members (Eppler et al., 2016)
- Ensure that at least two crew members develop proficiency operating the pre-positioned excavation and well-drilling equipment
- The pilot and backup have the lead for robot and rover operations, but other crew members also should be trained
- Train a member of the crew to lead the observation of the Transit of Earth and Moon during the CTM, but conduct the research as a group activity to foster solidarity early in the expedition
- Require that all crew members and mission control personnel receive training concerning the behavioral effects of isolation and confinement and the need to monitor each other's adjustment to the conditions.

An analysis of these abilities with regard to the current and candidate astronaut crew can be found in the full report.

5.0 CONCLUSION

The results of the task and ability analyses presented in this technical manual provide a concise representation of the work that is likely to be performed during the first human expeditions to Mars, and the abilities that will be needed by the explorers. Results highlighted in this technical manual should serve as valuable reference material for research and development teams who need to make informed design decisions, and for test teams who need to develop realistic verification scenarios for testing. For a more detailed exploration of the background, methodology, and results, please refer to the original task list (Stuster et al., 2018), and full 3-year project report (Stuster et al., 2019).

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APPENDIX A: ALL 158 SUMMARY TASK STATEMENTS RANKED BY CRITICALITY

Rank	Summary Task Statement	Frequency	Difficulty	Importance	Criticality
1	Perform science-related EVA functions during MSO.	3.679	4.036	4.286	12.000
2	Monitor systems and perform piloting functions during Mars Surface Ascent.	2.912	4.158	4.807	11.877
3	Perform piloting functions during MSD.	2.589	4.375	4.821	11.786
4	Interact/communicate with crew members directly during MSO.	4.638	2.298	4.672	11.609
5	Perform piloting functions during Earth Descent.	2.545	4.268	4.750	11.563
6	Perform piloting functions during Mars Orbit Injection.	2.386	4.246	4.860	11.491
7	Perform piloting functions during Mars Orbit.	2.556	4.241	4.691	11.487
8	Enter control inputs, manually/visually with gloved hand, to pilot Earth Ascent Vehicle (EAV) during launch and cruise to LEO/CLO.	2.772	4.000	4.702	11.474
9	Monitor systems/perform piloting functions during TEI.	2.800	3.893	4.732	11.425
10	Perform piloting functions during Earth Approach.	2.518	4.107	4.786	11.411
11	Assess displayed information, cognitively, to determine readiness to launch to LEO/CLO.	3.123	3.632	4.579	11.333
12	Conduct Extra-Vehicular Activity (EVA) to perform maintenance or retrieve items from outside the interplanetary space vehicle during Cruise to Mars.	2.246	4.491	4.596	11.333
13	Monitor displays and verify configurations before and during launch to LEO/CLO	3.554	3.333	4.439	11.326
14	Monitor systems during Earth Descent.	3.481	3.382	4.436	11.300
15	Perform monitoring functions in surface habitat and modules to ensure crew/system health during MSO.	3.897	3.000	4.386	11.283
16	Enter/exit surface habitat, manually while wearing pressure suit and helmet, during MSO.	3.544	3.246	4.474	11.263
17	Perform medical diagnoses and evaluations, cognitively, during Mars Surface Operations.	2.690	4.053	4.517	11.260
18	Perform robot-related functions during MSO.	3.527	3.750	3.982	11.259

Rank	Summary Task Statement	Frequency	Difficulty	Importance	Criticality
19	Perform geology-related science functions in surface habitat or modules during Mars Surface Operations.	3.491	3.754	4.000	11.245
20	Assess displayed information, cognitively, to determine readiness for TMI maneuver.	3.018	3.571	4.643	11.232
21	Monitor crew behavioral health/respond to behavioral health issues during Mars Surface Operations.	3.133	3.559	4.517	11.209
22	Monitor systems to ensure proper functioning during CTM.	3.897	2.983	4.328	11.207
23	Perform medical diagnoses and evaluations, cognitively, during Cruise to Mars.	2.649	4.055	4.491	11.195
24	Respond to medical emergencies, following procedures and with equipment provided, during Cruise to Mars.	1.948	4.509	4.724	11.181
25	Perform surface rover driving functions during MSO.	3.464	3.411	4.304	11.179
26	Respond to medical emergencies, following procedures and with equipment provided, during MSO.	2.069	4.263	4.825	11.157
27	Perform surface EVA physical functions on foot during MSO.	3.298	3.482	4.368	11.149
28	Adjust system controls, manually during buffetted descent, in response to displayed information.	2.673	3.870	4.585	11.128
29	Respond to technical emergencies, following procedures and with equipment provided, during CTM.	2.140	4.053	4.930	11.123
30	Monitor systems during Mars Surface Descent.	3.148	3.444	4.509	11.102
31	Perform tests and examinations, physically, to support medical diagnoses during Mars Surface Operations.	2.741	3.860	4.483	11.084
32	Perform biology-related science functions in surface habitat or modules during Mars Surface Operations.	3.474	3.579	4.018	11.070
33	Exercise daily using onboard equipment during CTM.	4.390	2.179	4.500	11.068
34	Enter control inputs, manually/visually with gloved hand, to configure/operate Earth Ascent Vehicle (EAV) before/after launch.	2.821	3.614	4.625	11.060
35	Perform surface rover operation functions during MSO.	3.364	3.509	4.182	11.055
36	Conduct science and planning functions during CTM.	3.821	3.625	3.607	11.054
37	Monitor systems to ensure proper functioning during CTE.	3.778	3.074	4.185	11.037

Rank	Summary Task Statement	Frequency	Difficulty	Importance	Criticality
38	Perform surface rover navigation functions during MSO.	3.375	3.446	4.214	11.036
39	Respond to medical emergencies, following procedures and with equipment provided, during Cruise to Earth.	2.000	4.327	4.696	11.024
40	Perform human research-related science functions in surface habitat or modules during MSO.	3.534	3.448	4.017	11.000
41	Perform tests and examinations, physically, to support medical diagnoses during Cruise to Mars.	2.759	3.877	4.362	10.998
42	Conduct communications checks and communicate observations/evaluations to crew and MCC personnel, verbally using communications system during MSO.	4.123	2.500	4.368	10.991
43	Perform electronics/computers maintenance/repair functions in surface habitat or modules during MSO.	2.983	3.596	4.404	10.983
44	Perform maintenance/repair/monitoring functions during surface EVA operations during MSO.	3.071	3.589	4.321	10.982
45	Respond to technical emergencies, following procedures and with equipment provided, during CTM.	2.109	4.055	4.818	10.982
46	Perform medical diagnoses and evaluations, cognitively, during Cruise to Earth	2.696	3.964	4.321	10.981
47	Assess displayed and aural information, cognitively, to determine appropriate course of action during CTM.	3.018	3.298	4.649	10.965
48	Perform maintenance/repair functions in surface habitat or modules during Mars Surface Operations.	3.089	3.464	4.393	10.946
49	Conduct training to preserve/learn skills during CTM.	3.661	2.931	4.322	10.914
50	Perform construction-related EVA functions during MSO.	2.768	3.750	4.393	10.911
51	Perform medical treatments during MSO.	2.328	3.965	4.586	10.879
52	Perform tests and examinations, physically, to support medical diagnoses during Cruise to Earth	2.782	3.741	4.327	10.850
53	Conduct maintenance functions during Cruise to Mars.	3.246	3.333	4.246	10.825
54	Perform post-Mars Descent maneuver functions.	2.333	3.907	4.556	10.796
55	Conduct maintenance functions during Cruise to Earth.	3.333	3.296	4.167	10.796

Rank	Summary Task Statement	Frequency	Difficulty	Importance	Criticality
56	Monitor displays and verify configurations before and during TMI	3.246	3.175	4.368	10.789
57	Perform science-related EVA functions with heavy equipment during Mars Surface Operations.	2.877	3.964	3.946	10.788
58	Adjust systems to ensure proper functioning during CTM.	2.879	3.534	4.362	10.776
59	Monitor systems during Mars Orbit Injection.	3.018	3.263	4.491	10.772
60	Perform initial installation/activation/inspection of surface habitat systems during MSO.	2.386	3.649	4.737	10.772
61	Conduct piloting functions during Cruise to Earth.	2.407	3.852	4.500	10.759
62	Prepare/eat meals in surface habitat during MSO.	4.293	1.982	4.466	10.741
63	Conduct piloting functions during Cruise to Mars.	2.509	3.930	4.298	10.737
64	Monitor systems during Earth Approach.	3.200	3.109	4.418	10.727
65	Monitor EVA systems during EVA during MSO.	3.411	3.070	4.246	10.727
66	Use interplanetary ship waste management systems for liquid/solid waste during CTM.	4.172	2.375	4.172	10.720
67	Adjust controls/attachments, manually with gloved hands, to configure suit/displays before/during/after launch from LEO/CLO.	2.782	3.473	4.455	10.709
68	Assess displayed and aural information, cognitively, to determine appropriate course of action during CTM.	3.164	3.200	4.345	10.709
69	Perform emergency functions in surface habitat or modules during Mars Surface Operations.	2.052	3.810	4.845	10.707
70	Conduct communications checks and communicate observations/evaluations to other crew and MCC personnel during Earth Surface Descent.	3.855	2.473	4.364	10.691
71	Prepare for Mars Surface Ascent maneuver.	2.263	3.737	4.684	10.684
72	Conduct navigation functions during Cruise to Mars.	2.709	3.636	4.333	10.679
73	Configure systems for Mars Orbit ops and descent.	2.321	3.625	4.709	10.656
74	Adjust systems to ensure proper functioning during CTE.	2.944	3.389	4.315	10.648
75	Conduct navigation functions during Cruise to Earth.	2.698	3.547	4.377	10.623

Rank	Summary Task Statement	Frequency	Difficulty	Importance	Criticality
76	Monitor systems during Mars Orbit operations	3.255	3.089	4.268	10.612
77	Prepare/eat meal, manually, using interplanetary ship food hydration/heating equipment/galley during CTE.	4.345	1.963	4.291	10.599
78	Conduct science and planning functions during CTE.	3.722	3.278	3.593	10.593
79	Exercise daily using onboard equipment during CTE.	4.286	2.073	4.232	10.591
80	Conduct communications checks and communicate observations/evaluations to crew and MCC personnel, verbally using communications system during MOI.	3.400	2.727	4.463	10.590
81	Conduct EVA to perform maintenance or retrieve items from outside the interplanetary ship during CTE.	2.036	4.196	4.357	10.589
82	Perform post-Mars Ascent maneuver functions.	2.286	3.772	4.526	10.584
83	Perform medical treatments during Cruise to Earth.	2.273	3.870	4.436	10.579
84	Perform construction-related EVA functions with heavy equipment during Mars Surface Operations.	2.375	3.911	4.286	10.571
85	Conduct communications checks and communicate observations/evaluations to crew and MCC, verbally using communications system prior to and during EA.	3.673	2.473	4.418	10.564
86	Conduct communications checks and communicate observations/evaluations to crew and MCC, verbally using communications system during launch to LEO/CLO.	3.965	2.158	4.421	10.544
87	Inspect/prepare/ deploy surface rover during MSO.	3.000	3.439	4.105	10.544
88	Use surface habitat waste management systems for liquid/solid waste during MSO.	4.138	2.281	4.103	10.522
89	Conduct communications checks and communicate observations/evaluations to crew and MCC personnel, verbally using communications system during CTM.	3.982	2.429	4.107	10.518

Rank	Summary Task Statement	Frequency	Difficulty	Importance	Criticality
90	Conduct communications checks and communicate observations/evaluations to crew and MCC personnel, verbally using communications system during MSA.	3.368	2.696	4.429	10.493
91	Prepare/eat meal, manually, using interplanetary ship food hydration/heating equipment/galley during CTM.	4.237	1.982	4.254	10.474
92	Perform medical treatments during Cruise to Mars.	2.158	3.786	4.526	10.470
93	Perform surface rover maintenance during MSO.	2.786	3.571	4.089	10.446
94	Conduct communications checks and communicate observations/evaluations to crew and MCC personnel, verbally using communications system during MSD.	3.382	2.745	4.315	10.442
95	Adjust controls in surface habitat or modules to ensure proper functioning of systems during MSO.	3.211	2.895	4.333	10.439
96	Perform pre- and post-EVA inspection and planning tasks during Mars Surface Operations.	3.241	3.018	4.158	10.417
97	Conduct communications checks and communicate observations/evaluations to crew and MCC personnel, verbally using communications system during MSO.	3.527	2.630	4.255	10.411
98	Perform greenhouse/plant growth-related functions in surface module during Mars Surface Operations.	3.589	2.946	3.875	10.411
99	Prepare for Mars Surface Ascent during MSO.	2.069	3.586	4.741	10.397
100	Use interplanetary space vehicle waste management systems for liquid/solid waste (i.e., toilet/bodily function) during CTE.	4.185	2.113	4.093	10.391
101	Perform exercise in surface habitat to maintain cardiovascular/muscle/ bone conditioning during MSO.	4.017	2.035	4.322	10.374
102	Perform planning and administrative functions, individually and with other crew members during MSO.	3.754	2.526	4.070	10.351
103	Conduct communications checks and communicate observations/evaluations to crew and MCC, verbally using communications system during Pre-TMI & TMI.	3.661	2.429	4.250	10.339

Rank	Summary Task Statement	Frequency	Difficulty	Importance	Criticality
104	Prepare for Mars Surface Descent maneuver.	2.236	3.527	4.564	10.327
105	Sleep for approximately eight hours each 24-hour period, during Cruise to Mars.	4.153	1.621	4.542	10.316
106	Perform robot maintenance functions during MSO.	2.818	3.661	3.818	10.297
107	Maintain space craft waste management systems during CTM.	3.542	2.579	4.051	10.172
108	Prepare for Earth Surface Descent.	2.370	3.200	4.600	10.170
109	Perform surface EVA communications during MSO.	3.526	2.439	4.175	10.140
110	Sleep for approximately eight hours each 24-hour period, during Cruise to Earth.	4.250	1.545	4.321	10.117
111	Perform training and skill refreshment in surface habitat during Mars Surface Operations.	3.186	2.810	4.119	10.115
112	Sleep in surface habitat during MSO.	4.203	1.483	4.397	10.083
113	Conduct refresher training during CTE.	3.127	2.815	4.127	10.069
114	Perform administrative/planning-related science functions in surface habitat or modules during MSO.	3.536	2.807	3.702	10.044
115	Conduct communications checks and communicate observations/evaluations to crew and MCC personnel, verbally using communications system during CTE.	3.768	2.161	4.107	10.036
116	Perform suit-related tasks before and after launch.	2.636	3.055	4.321	10.012
117	Respond to dental emergencies during MSO.	2.018	3.929	4.052	9.998
118	Maintain space craft waste management systems during CTE.	3.446	2.509	4.018	9.973
119	Prepare for Earth Approach.	2.327	3.130	4.509	9.966

Rank	Summary Task Statement	Frequency	Difficulty	Importance	Criticality
120	Administer medications during MSO.	2.724	2.947	4.224	9.896
121	Conduct communications checks and communicate observations/evaluations to MCC personnel, verbally using communications system during TEI.	3.123	2.491	4.281	9.895
122	Perform installation/activation/inspection of auxiliary systems during Mars Surface Operations.	2.836	3.089	3.964	9.890
123	Perform surface EVA habitability functions during MSO.	3.143	2.860	3.877	9.880
124	Prepare for Mars Orbit Injection aerobraking maneuver.	2.089	3.263	4.526	9.879
125	Take position and prepare vehicle, manually while wearing pressure suit and helmet, to prepare for launch from Mars Orbit.	2.250	3.246	4.368	9.864
126	Use surface habitat hygiene systems for cleaning during MSO.	3.948	2.105	3.793	9.847
127	Review procedures/checklists to prepare for Mars Orbit Operations and descent.	2.679	2.768	4.393	9.839
128	Use interplanetary space vehicle hygiene systems for cleaning during Cruise to Mars.	3.947	2.161	3.719	9.827
129	Adjust controls, manually with gloved hands, before and after launch to LEO/CLO.	2.821	2.807	4.193	9.821
130	Administer medications during Cruise to Mars.	2.707	2.860	4.241	9.808
131	Conduct installation functions during Cruise to Mars.	2.929	3.089	3.768	9.786
132	Respond to dental emergencies, following procedures and with equipment provided, during Cruise to Earth.	1.875	3.891	3.964	9.730
133	Perform surface habitat housekeeping during MSO.	3.810	2.158	3.759	9.727
134	Respond to dental emergencies, following procedures and with equipment provided, during Cruise to Mars.	1.807	3.947	3.948	9.703
135	Use interplanetary space vehicle hygiene systems for cleaning during Cruise to Earth.	3.926	2.000	3.759	9.685

Rank	Summary Task Statement	Frequency	Difficulty	Importance	Criticality
136	Load/unload surface rover/trailer for MSO.	2.754	3.035	3.877	9.667
137	Prepare/eat meals during Earth Approach.	3.786	1.907	3.945	9.639
138	Use EDV waste management systems for liquid/solid waste during Earth Approach.	3.545	2.164	3.875	9.584
139	Administer medications during Cruise to Earth.	2.691	2.759	4.127	9.577
140	Use Earth Ascent Vehicle (EAV) waste management system for liquid/solid waste.	3.328	2.436	3.702	9.466
141	Conduct recreational activities, individually and as a crew, during Cruise to Earth.	3.821	1.537	3.982	9.341
142	Conduct installation functions during Cruise to Earth.	2.660	3.038	3.615	9.314
143	Perform administrative functions during CTE.	3.352	2.472	3.472	9.295
144	Perform administrative functions during CTM.	3.509	2.333	3.421	9.263
145	Conduct recreational activities, individually and as a crew, during Cruise to Mars.	3.828	1.411	3.966	9.204
146	Prepare/eat meal, manually, using Earth Ascent Vehicle (EAV) food hydration/heating equipment/galley during cruise to CLO.	3.448	2.018	3.719	9.186
147	Perform post-Earth Descent functions.	2.327	3.089	3.750	9.167
148	Perform 3D printer-related functions in surface habitat or modules during Mars Surface Operations.	2.732	2.911	3.393	9.036
149	Perform recreation/leisure activities in the surface habitat during Mars Surface Operations.	3.632	1.554	3.807	8.992
150	Enter vehicle and take position, manually while wearing pressure suit and helmet, to prepare for launch from LEO/CLO.	2.018	2.768	4.196	8.982
151	Enter vehicle/take position, manually while wearing pressure suit/ helmet, to prepare for launch to CLO.	2.125	2.607	4.232	8.964

Rank	Summary Task Statement	Frequency	Difficulty	Importance	Criticality
152	Perform surface rover habitability/logistics functions during MSO.	2.897	2.404	3.569	8.869
153	Use surface rover waste management systems for liquid/solid waste during MSO.	3.035	2.232	3.596	8.864
154	Prepare/eat meals in surface rover during MSO.	3.017	1.912	3.534	8.464
155	Conduct inventories and update records during CTE.	3.000	1.982	3.339	8.321
156	Sleep in surface rover during Mars Surface Operations.	2.661	1.873	3.732	8.266
157	Conduct inventories and update records during CTM.	2.864	1.965	3.345	8.174
158	Use emergency materials to contain/clean results of motion sickness during/after launch.	2.552	2.103	2.845	7.500