ERGONOMICS AND HUMAN FACTORS

ERGONOMICS AND HUMAN FACTORS IN SAFETY MANAGEMENT

Accident prevention is a common thread throughout every aspect of our society. However, even with the most current technological developments, keeping people safe and healthy, both at workplaces and at other daily activities, is still a continual challenge. When it comes to work environments, ergonomics and human factors knowledge can play an important role and, therefore, must be included in, or be a part of, the safety management as a cross-disciplinary area concerned with the understanding of actual work situations and potential variables. This multidisciplinary approach will ultimately ensure the safety, health, and well-being of all collaborators. The main goal of this book is to present theories and models, and to describe practices to foster and promote safer work and working environments.

This book offers:

- Examples of field practices that can be reproduced in other scenarios
- Applications of new methods for risk assessment
- Methods on how to apply and integrate human factors and ergonomics in accident prevention and safety management
- Coverage of human factors and ergonomics in safety culture
- New methods for accident analysis

This book is a compilation of contributions from invited authors organized in three main topics from eleven countries and is intended to cover specific aspects of safety and human factors management ranging from case studies to the development of theoretical models.

Hopefully, the works presented in the book can be an inspiration for translating research into useful actions and, ultimately, making a relevant and tangible contribution to the safety of our daily and work settings.

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Contents

SECTION II Safety and Human Factors in Training and Simulation

SECTION III Models and Other Topics

Preface

This book is a compilation of contributions from invited authors organized in 18 chapters and grouped by three main topics. All of the authors were invited after their participation in the 2nd and 3rd International Conferences on Safety Management and Human Factors, which are affiliated with the International Conference on Applied Human Factors and Ergonomics.

This book has contributions from 60 authors from 11 countries, and it intends to cover specific aspects of safety and human factors management, ranging from case studies to the development of theoretical models.

The chapters are organized into three different topics, which will allow readers to clearly identify the main focus of each chapter.

The first section, comprised of the first seven chapters, is dedicated to occupational safety.

Chapter 1, from Carvalho and Melo describes the matrix-based technique used to perform occupational risk assessment. They claim that this approach has advantages in occupational risk assessments, namely, because it allies the advantages of both the quantitative and qualitative approaches and overcomes some of their limitations. In this chapter, Carvalho and Melo present a study to evaluate the reliability of the matrix-based approach.

Chapter 2, from Debnath et al., discusses regulatory, organizational, and operational issues in road construction safety in Australia. In their study, from the state of Queensland, Australia, they examine how well the tripartite (regulatory, organization, and operational) framework functions. The study identifies several factors influencing the translation of safety policies into practice, including the cost of safety measures in the context of competitive tendering, the lack of firm evidence of the effectiveness of safety measures, and pressures to minimize disruption to the traveling public.

The contribution of Gutiérrez and Sánchez, in Chapter 3, describes the development of an occupational health and safety management system for manufacturing companies in Mexico using factorial analysis. Their research, based on a survey conducted among 32 Mexican manufacturing companies, attempts to give clarity to Mexican manufacturing companies in the creation of a unique management system that covers occupational safety aspects and allows them to accomplish government as well as global clients' requirements.

In Chapter 4, from Rodrigues et al., the authors present a study developed within the Portuguese furniture industrial sector, in which they characterize the safety performance of the sector, namely, by analyzing the corresponding occupational accidents and identifying the key unsafe conditions that can originate these accidents. Using a sample of 14 Portuguese companies of this sector, they also analyzed the applicability of the Safety Climate in Wood Industries as a tool to monitor companies' safety performance and assess the safety climate within those companies. Among other results, they found a strong positive linear correlation between safety climate scores and the companies' safety performance.

Väyrynen et al. present a review about health, safety, environment, and quality (HSEQ) management in Chapter 5. They describe a model used for HSEQ assessment that has been developed and applied within many Finnish company networks. They also focus on small- and medium-sized enterprises (SMEs) and their work systems with outcomes, their HSEQ assessment results, and the concepts of sustainability and safety culture. The authors suggest that such a model can promote productivity and conformity within a work system with more desired outcomes.

In Chapter 6, Vidal et al. develop an analysis of work accidents based on the ergonomic point of view. They present the methodological framework for this analysis, trying also to show its application. They discuss some contemporary visions about work accidents and attempt to cross them with some modern trends of approaches used in ergonomics. They finish by presenting the possible impact of their approach on practice in accident prevention.

Chapter 7, the last chapter of Section I, by Waefler et al., describes a project safety management information system (S-MIS), which aims to develop an information system that supports decisions in safety management. According to the authors, the S-MIS project attempts to provide industry with reliable proactive indicators, as well as a support for decision making in safety management. Based on a pilot project, the S-MIS process has been analyzed for its appropriateness to provide decision makers in safety management with a better quantitative information base. In the authors' opinion, the process still needs to be optimized.

Section II is dedicated to the specific topic of safety and human factors in training and simulation and encompasses four different chapters.

Chapter 8, from Maciel et al., aims to analyze tasks and electrical system operators' potential errors to propose corrective strategies and improvements in the design process and operating systems using hierarchical task analysis and the systematic human error reduction and prediction approach. The results revealed that the method employed is capable of distinguishing the main operator tasks, according to their decision making, to maintain proper system operation.

In Chapter 9, Nazir et al. compare the results of convectional training methods and those based on immersive virtual environments employed in process industries. Two groups of participants are trained according to either a conventional training approach or an immersive virtual environment. The performance of operators is measured in real time by means of suitable and well-defined key performance indicators. The results show that participants trained with immersive virtual environments react significantly more quickly and accurately to a simulated accident scenario than those trained with a conventional approach.

Rocha et al., in Chapter 10, discuss the importance of knowledge management for counterbalancing the process of loss of skills at work, as the social actor responsible for creating the procedures is far from the reality experienced in the field, causing safety problems at work. They argue that the disconnection between what is written and what is real is the absence of spaces of discussion at work that allow the sharing of knowledge or the possibility to externalize strategies and actions that can be used when managing the difficulties in the field.

In Chapter 11, Wagner et al. describe an experimental study with 23 untrained volunteers where they analyzed how the occurrence of an evacuation assistant influences the behavior and the emotional state of evacuees while acting in different conflict situations. Their results give important indications to improve evacuation situations. They have also developed an agent-based simulation model to allow an evacuation, through simulating the cognitive processes of agents in the simulation environment. The authors concluded that the model was capable of reproducing empirically observed human behavior, and it enables simulation scenarios with a high degree of realism.

In Chapter 12, Inaba et al. finish Section II describing an interactive educational game to learn about human error. The aim is the development of a serious game in which individuals can effectively learn the mechanisms of a slip. Using the game, people become immersed in situations that allow them to react to risks and learn about risks without exposing themselves to real danger.

Finally, Section III is dedicated to safety and human factors models and related topics, as well as some other mixed topics, as described briefly in the following paragraphs.

In Chapter 13, Jansen et al. discuss how our daily and work lives are filled with interruptions and transitions from one task to another, resulting in a fragmented workflow. He proposes the transitional journey maps, creating workflow visualizations as a way to produce reflections about interruptions in work activities. He approached two organizations with the request to study human information processing activities at work, the Dutch National and the European Space Operations Centre.

Klockner and Toft talk about the missing links in system safety management in Chapter 14. Their research starts with the premise that organizations have no memory and accidents recur, and that organizations and safety regulators often identify what appear to be reoccurring patterns and themes of the contributing factors identified by safety occurrence investigations. The ongoing frustration is how lessons can be learned from what has already occurred and how that information can be used to identify areas and aspects of organizational safety management systems that are negatively contributing to safety occurrences.

In Chapter 15, Murata uses the Bayesian estimation method to predict the risk of driving drowsiness. The aim of this study was to predict in advance drivers' drowsy states with a high risk of encountering a traffic accident and prevent drivers from continuing to drive under drowsy states. His results indicate that the proposed method could predict in advance the point in time with a high risk of a virtual crash before the point in time of a virtual accident when the participant would surely have encountered a serious accident with a high probability.

Schlacht, in Chapter 16, tries to inspire specialists to use the space missions design, system, and simulation as a model for realizing possible innovation of safety procedures in regular critical and dangerous situations. Assuming the safety-critical systems and space environments share many of the problems regarding the support of human life, the author proposes that space missions can be used as a model to learn how to increase safety and improve user–system interaction.

Chapter 17, from Tappura and Nenonen, proposes a scheme for categorizing effective safety leadership facets, considering that this concept is a key factor for promoting safety performance in organizations. The authors based their work on a literature review, as well as on interviews carried out in a Finnish organization. They concluded that both the transactional and transformational facets of safety leadership should be exercised and developed.

The last chapter of the book, authored by Zixian Yang and Therma Wai Chun Cheung, presents a work on the topic of upper limb repetitive strain injury (RSI) in women involved in housework. The authors have analyzed this problem and confirmed that female homemakers who need to carry out unpaid housework make up a major proportion of patients with upper limb RSI referred to an occupational therapy outpatient clinic in Singapore. According to the authors, their findings provide a logical explanation for the high prevalence of upper limb RSI in women.

On behalf of the entire team that was involved in the development of this book, we are very proud to provide a very broad scope of contributions, which has included some case studies, examples, solutions, models, and challenges presented and proposed here by a broad group of authors from a wide array of disciplines and countries. We greatly enjoyed working with the contributors to this book on the topic of Human Factors in Safety Management. We also want thank the contributors for sharing their findings and insights, as well as the reviewers of the initial versions of these chapters for their essential contribution. We hope that the works presented here can be an inspiration for translating research into useful actions and, ultimately, make a relevant and tangible contribution to the effective improvement regarding the safety of our daily and work settings.

Editors

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16 Space Missions as a Safety Model

Irene Lia Schlacht

CONTENTS

16.1 INTRODUCTION

From the International Space Station to extreme environments on Earth, people are risking their lives every day to enhance scientific progress and perform their work. To do so, they work in very dangerous environments under extreme working conditions that seriously affect their safety and performance. Safety is defined in the *Oxford Dictionary* as "the condition of being protected from or unlikely to cause danger, risk, or injury" (Oxford Dictionary 2015). "Safety first"—it is well known that safety is the most important factor that is always given top priority in every project, especially in recent decades. In addressing particularly dangerous contexts, such as space missions, safety requirements need even more attention. These requirements need to be considered in the design approach of the overall system structure and when testing the system with dedicated simulations.

This chapter addresses the improvement of safety in working and living conditions using space missions as a model and starting from the results presented at the Applied Human Factors and Ergonomics (AHFE) 2015 conference (Schlacht et al. 2015c). It presents research performed regarding safety optimization in space missions using

- The Integrated Design Process (IDP)
- A sustainable system
- A mission simulation

The final section describes why the transfer of research and design solutions can be valuable in terms of addressing safety problems faced in extreme or dangerous environments on Earth.

16.2 INTEGRATED DESIGN PROCESS VERSUS SAFETY

The space scenario was selected as being characterized by the most life-threatening challenges. Indeed, this context includes the most extreme and adverse factors for human life, such as radiation, absence of pressure and oxygen, physical adaptation to microgravity, social isolation, and spatial confinement (Schlacht 2011, 2012). A very specific and small range of users also characterizes this context: astronauts. On Earth, life-threatening challenges are not rare either, but they affect a wide range of users in comparison to space missions. For instance, the literature on accidents such as Chernobyl, Bhopal, and Deepwater Horizon highlights the catastrophic consequences that those accidents brought with them. In contrast, in space every user has a fundamental role, and his or her safety is strictly related to the safety of the entire mission. This is why in space, the approach used to support the safety of each individual needs to be optimal. User-centered design is the foundation for this.

One option for optimizing safety in space missions is to use computer simulations. "To prepare for a potential disaster, decision-support systems based on computer simulations can enable safety managers to determine mitigation projects, and better understand the different risks associated with operations. For example, if toxic gases are released, there is a need to predict where the gas plume will go, how far it will extend, the expected concentration of toxins, and the health and safety consequences" (Rabelo et al. 2005, p.1). However, the space context is very particular; it can be compared to an aquarium where each element has a strong influence on the others and where it can be very difficult to analyze with a computer simulation each element separately in order to verify the whole system. For these reasons, all of the human factors interacting with the system need to be part of the simulation. So, if toxic gases are released in a space station, the astronauts cannot just escape to the outside. This may also interact with other safety elements that need to be simulated, such as psychological factors. With computer simulations, it is difficult to consider all the factors and their interactions at the same time, but it is easy to consider each factor separately. However, as Aristotle said, "The whole is greater than the sum of its parts." Applied to our case, this means that the whole needs to be simulated at the same time in order to achieve a better result than through the simulation of individual factors. In other words, a holistic approach needs to be used (covering all the aspects together as a whole; *holos* = all) (Schlacht 2012; Bandini Buti 2011).

To achieve this, the simulation for the space environment is done by simulating physically or virtually (with virtual simulation) each interaction factor within the IDP. The IDP is a design model developed by the author to approach this particular context of design. The IDP combines user-centered design, a holistic approach, and human factors needs to achieve an enjoyable, comfortable, and safe environment for users who need to perform under extreme and life-threatening conditions.

Specifically, the IDP integrates operational, physical, environmental, psychological, and socio-cultural factors. It is based on a human-centered approach and a holistic methodology to support the human side of the project, such as cultural dimensions within the technological interaction. The human-centered design focuses on three techniques: designing the experience of the user (user experience), designing together with the user (participatory design), and designing by identifying oneself with the user (empathetic design). The holistic methodology aims to support the user in relation to the system and is composed of the interrelations among three mainly quality-oriented methods: a multidisciplinary team (integrating humanities), concurrent design (concurrently working together with all the disciplines on each phase of the project life cycle), and support through dedicated development of human–machine–environment interactions. The application of the design model in respect to the current methodology increases safety and productivity because it supports usability, livability, and flexibility, which are very important elements in extreme and emergency contexts (Schlacht et al. 2012b) (Figure 16.1).

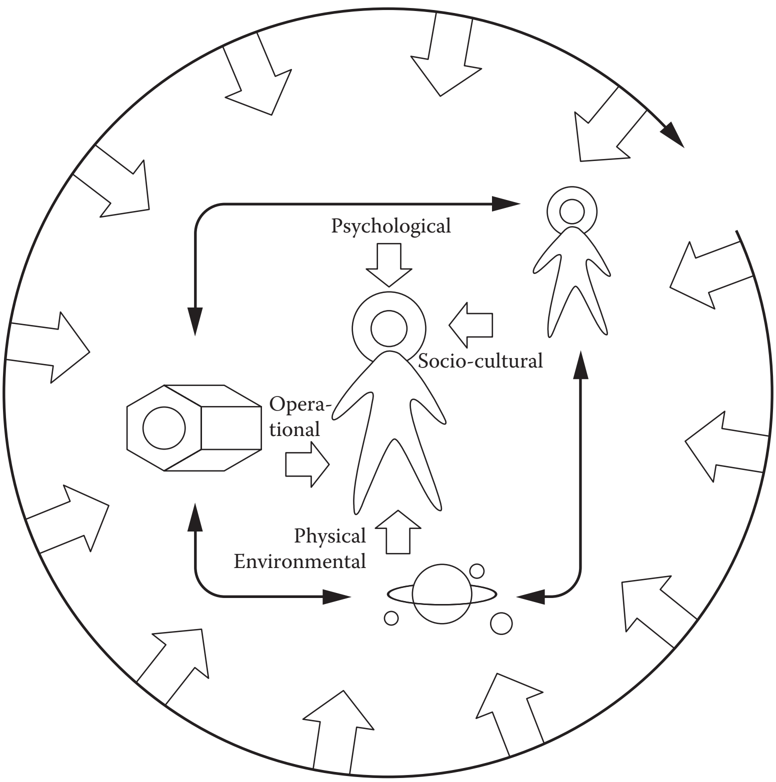

FIGURE 16.1 IDP design model. In the IDP graphical representation, the circular arrow is the concurrent design, the arrows in the circle are the different disciplines, the human-machine-environment interrelation is represented inside the circle, and the human-centered design is represented with the human in the middle surrounded by the five human factors: operational, environmental, physiological, psychological, and socio-cultural. (Copyright Schlacht.)

16.3 SUSTAINABLE SYSTEM VERSUS SAFETY

"Space stations are working places operating in extreme and isolated environments. In isolation, having no access to resources, these places need to be self-sufficient and sustainable and be able to reuse their resources" (Schlacht et al. 2015a, p. 1). Sustainability of the system is a key factor for safety (Figure 16.2).

Sustainability is related to safety in two complementary ways: the first is operational and technical and related to achieving a "closed-loop system" that optimizes its performance through precise management of system resources and operations (e.g., recycling of goods and *in situ* energy production); the second is sociopsychological and related to the "slow design" approach, which uses sustainability to create a user experience that increases psychological well-being and user reliability in isolated environments (e.g., by supporting direct production and consumption of goods as a form of qualitative user experience) (Schlacht et al. 2015a).

The integration of safety and sustainability objectives is necessary to achieve optimal safety and performance, as well as mission success.

From an operational and technical perspective, a closed-loop system that is autonomous, self-sufficient, and regenerative is necessary in remote locations with limited or absent infrastructure, transportation, and resources (Bannova and Bell 2011). A closed-loop or self-sufficient system requires no additional input, as it employs recycling of goods and *in situ* energy production to perform system operations. In creating a closed-loop system for extreme environments such as space, the objectives of sustainability can complement and even enhance user safety. Through a comprehensive life cycle analysis, the system structure can be designed to sustain an

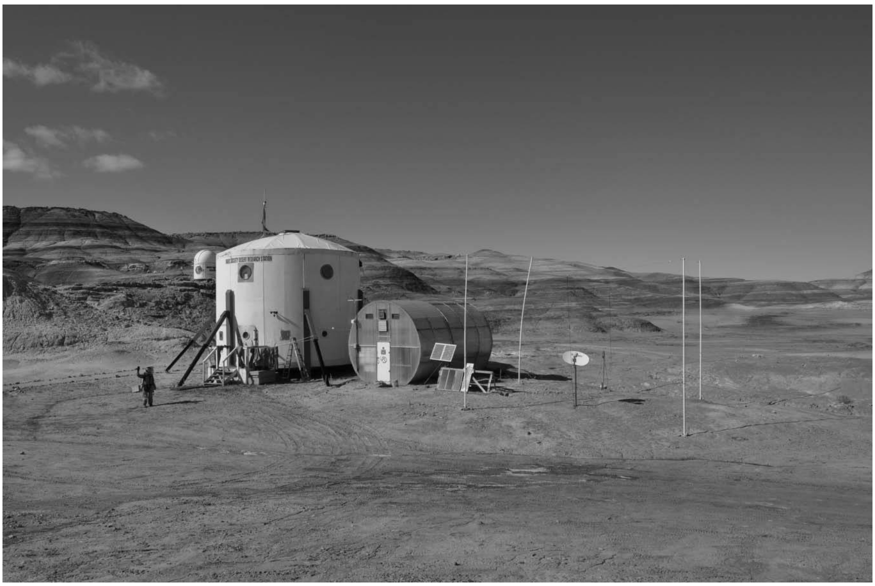

FIGURE 16.2 Mars Desert Research Station (MDRS) isolated in the middle of the "Martian desert."

equilibrium that supports safety and optimizes the use and reuse of resources for the duration of the mission (Takata and Kimura 2003). Using this holistic approach toward all system elements and their interactions, the closed-loop system is optimized and preserved. Consumed resources once regarded as waste products become inputs for other operations; by-products of production and consumption processes are harvested as resources as well. Methods of decontamination and recycling of materials for reuse are devised to optimize product recovery and minimize user hazard (e.g., use of bacteria on mycellium to break down toxic materials). Efficient *in situ* energy increases reserves for periods when additional energy is required, such as during system failure. The identification of relationships between safety and sustainability motivates efforts to find new and improved organization, planning, and design solutions for optimal performance and user safety, and supports the design of closed-loop systems for isolated environments, from space to Earth (Schlacht et al. 2015a) (Figure 16.3).

From a sociopsychological perspective, the slow design supports sustainability addressing human needs that improve and sustain the psychological health of users. This is imperative for safety during situations with limited human interaction, confined environments, and conditions of isolation (Bannova 2014). "A human who is not reliable psychologically may make mistakes and disrupt the small and fragile closed-loop system of a Space station" (Schlacht et al. 2015a). Research on the effect of isolation and confinement on humans has broadened to encompass states of consciousness, stress, health, small group dynamics, personnel selection, crew training, and environmental engineering (Harrison et al. 1990). Improving and sustaining the psychological well-being of users can improve human–machine–environment interaction and increase the probability of user safety and survival. A design approach that supports the user's quality of life is strictly related to the equilibrium of the system (Ceppi 2012). The slow design approach enforces quality in the design approach by supporting sustainability and equilibrium in the system (Schlacht et al. 2015a). "Slow Design means cultivating quality: linking products and their producers to their places of production and to their end-users who, by taking part in the

FIGURE 16.3 Technical system for recycling water at MDRS. (Copyright Schlacht 2010.)

FIGURE 16.4 Experiencing sustainable food production at MDRS. (Copyright Schlacht 2010.)

production chain in different ways, become themselves coproducers" (Capatti et al. 2006). Principles of slow design can facilitate the design of a system that reduces stress, improves intellectual processing, and boosts overall morale (Schlacht et al. 2015a). By encouraging user interaction with the production and consumption of goods, slow design enables communication, control, and feedback. This improves overall mental health and perception and enables successful execution of operational tasks and emergency response, thus supporting overall safety (Figure 16.4).

16.4 MISSION SIMULATION VERSUS SAFETY

On the basis of the IDP, three mission simulation scenarios were investigated from the safety perspective in order to increase safety in particularly life-threatening environments:

1. MDRS (2-week simulation): The case of the Mars Desert Research Station (MDRS) in Utah, where a crew of six members took part in a real simulation of a space mission, testing safety, user interfaces, and procedures
2. ExoLab (1-day simulation): The International Lunar Exploration Working Group (ILEWG) mission, where a four-member crew in a basic container tested safety procedures for extra vehicular activity (EVA) on the Moon and their potentiality for application on Earth
3. V-ERAS (virtual simulation): The Mars Society mission, where a crew of four members took part in a virtual simulation of a Mars mission, testing safety, user interfaces, procedures, and reduced gravity

A safety factor being specifically studied in terms of human interaction is habitability, which is defined as "the usability of the environment" (Blume Novak 2000). During selected missions, safety and performance have been investigated with the help of the "habitability debriefing" developed by the author. The habitability debriefing is a new instrument for the analysis of safety and performance based on the IDP presented here (Hendrikse et al. 2011; Schlacht et al. 2012a). During each simulation mission, the debriefing was performed by all crew members together reporting the result as a group and anonymously. In order to increase the overall system safety and performance, the methodological aim was to let the group of users collectively discuss each possible problem and problem solution covering all the different human factors aspects. To cover all the human factors aspects, the discussion was guided in particular to operational, psychological, socio-cultural, environmental, and physiological factors. As a part of the IDP, a holistic approach was used (covering all the aspects together as a whole) (Schlacht 2012; Bandini Buti 2011). This approach is quite different from the traditional approach, where each crew member is questioned individually and each factor is studied separately. For example, operational problems are traditionally investigated after the mission, with each user facing a team of experts, while in the habitability debriefing, operational problems are investigated in relation to and in parallel with psychological, socio-cultural, environmental, and physiological factors, and the investigation is carried out jointly by all crew members during the mission (again, "the whole is greater than the sum of its parts").

16.4.1 MDRS

At the MDRS in the Roswell desert in Utah, every year a rotating crew of six members simulates a mission of the Moon–Mars scenario, testing safety as well as factors such as human interaction and procedures (Foing et al. 2010, 2011; Schlacht et al. 2010; Voute 2010; Mangeot et al. 2012). Research performed at the MDRS is optimal for testing and optimizing mission safety, in particular considering the specific desert surrounding the station, which is a perfect analog of the Mars environment: the natural reserve of the San Rafael Swell, a red-colored desert in Utah (Mars Society 2014) (Figures 16.5 through 16.7).

FIGURE 16.5 Working and living inside MDRS. (Copyright Schlacht 2010.)

FIGURE 16.6 Equipment safety check before EVA at the MDRS. (Copyright Schlacht 2010.)

FIGURE 16.7 EVA in the Martian desert during mission simulation at the MDRS. (Copyright Schlacht 2010.)

To create the optimal environment for the simulation, each individual factor needs to be planned and organized, such as the environment and the architecture of the space station; the system, which needs to be as sustainable as possible; the equipment; the behavioral procedure; and the hierarchy, selection, and training of the crew. Indeed, the organization of a simulation campaign is a complex procedure related to several factors and has to take into account specific rules.

At the MDRS, the system has been developed to give the greatest possible feeling of an autonomous system: the energy is provided by batteries, the communication connection is also autonomous, and the water is recycled for use in flushing the toilet. This is close to the concept of sustainability and autonomy. However, in space, the recycling rate of the water is much higher and reached 90% in the International Space Station.

To increase the credibility of the simulation, each subject needs to mimic a real space mission. One of the most important restrictions is the confinement in the habitat, with no possibility to escape without authorized EVA. The EVAs themselves need to be performed taking into account and applying all the regulations and equipment as in a real mission.

To give a better understanding of the MDRS simulation, the main points of the structure are described below.

- Crew composition: Usually mixed gender (men and women).
- Crew selection: Based on motivation and profiles.
- Crew structures and hierarchies: The crew has a sound structure with fixed tasks. There are six main roles that need to be covered: commander, executive officer, crew engineer, health and safety officer, journalist, and crew scientists (e.g., human factors researcher, geologist, and biologist). Extra roles outside the crew are campaign director, mission support, and project scientists.
- Training: Around 6 months before the mission, crew meetings are organized via remote conference calls in an attempt to accommodate the different goals and instruct the members to follow the strict safety rules and ethical restrictions of the station.
- Mission schedule: During the 2 weeks of the mission, each crew member carries out planned tasks, including scientific research, social activities, and station maintenance, in accordance with the simulation requirements (Figure 16.8).

  The isolation in a space analog environment such as the Utah desert, the strict procedures, and the crew hierarchy are some of the constraints that make this mission simulation an optimal scenario for verifying, testing, and increasing safety in extreme contexts. The methodology used to achieve a deep understanding of safety and performance problems concerns the application of the habitability debriefing. The debriefing is performed the day before the end of the mission. In complete privacy, the crew is guided for 90 min by a strict procedure regarding multidisciplinary analysis and collective discussion of the overall mission. The main mission problems and possible solutions are discussed from the perspectives of safety,

FIGURE 16.8 Soil measurement during MDRS mission simulation. In the image, the gloves are removed to interact with the instrument. Dedicated instruments are needed to perform a safe and successful mission.

performance, and comfort by the crew alone. Regarding the results during the 2014 MDRS mission, six crew members consisting of male and female members with international identities were able to spend 2 weeks simulating life on Mars. The human factors discipline was integrated and evaluated during the simulation to find problems and solutions, as well as propose implementation recommendations to increase the overall system performance.

- Find problems and solutions: Socio-cultural, psychological, operational, environmental, and physiological aspects were investigated. Operational aspects emerged as the most frequently discussed problem; in particular, communication was the most frequently recurring topic associated with this problem (Table 16.1). The main problems and solutions referred to increasing the quality of
  - Communication (as operational factors)
  - Equipment and structure (as operational, psychological, and environmental factors)
  - As a solution, to increase the overall system performance the crew proposed to improve the design of the equipment (particularly regarding EVA, toilet, and habitat structure) and the communication (particularly regarding manual and guideline)

In conclusion, in particular extreme and isolated contexts, safety, performance, and comfort are elements that are strongly correlated. A very uncomfortable scenario in a Mars mission will influence the performance and, as a consequence, also impact the safety of the crew.

TABLE 16.1
Problems and Solutions Voted as Most Important and Discussed by the Crew during the MDRS Mission (November 2014)

Problem (P)	Problem	Solution	Field	Crew Vote
P1: EVA equipment	Space suit fatigue, CO_2 buildup, poor air circulation, helmet fogging	Better design of air distribution; sensors; water cooling system; antifog system	Psychological—EVA	6/6
			Operational—EVA	6/6
P2: Toilet smell	Toilet smell	Increase ventilation; difficult to clean the room (new design); closable trash; more frequent flushing (recycling water)	Psychological—IVA	6/6
			Environmental—IVA	5/6
P3: Mission control communication	Lack of transparency and knowledge transfer	Manual, guideline improvement	Operational—IVA	6/6
P4: Station incomplete structure	Fake tunnel "breaking" simulation	Finish the tunnel and roof over the porch of the engineering airlock	Operational—IVA	6/6
P5: Communication on maintenance	Limited flexibility to make easy fixes; unclear what maintenance requires mission approval	Manual and guidelines improvement	Operational—IVA	6/6

16.4.2 ExoLab

The ExoLab mission simulation consisted of testing the safety and performance during a specific scenario related to a communication breakdown during EVAs. In the following, the mission results will be described as presented during the International Astronautical Conference (Schlacht et al. 2015b) (Figures 16.9 and 16.10).

This simulation addressed the context of building a minimum autonomous modular architecture for the Moon and extreme environments on Earth. The simulation was also performed to investigate the potential use for art- and science-related applications. More specifically, ExoHab and ExoLab have been set up as technical mock-ups at the European Space Research and Technology Centre (ESTEC) of the European Space Agency (ESA) in the Netherlands for the purpose of multidisciplinary mission simulation (Schlacht 2011, 2012; Schlacht et al. 2015b).

The structural project is based on particular restrictions in order to be applicable in extreme environments. These restrictions were to organize a living space for two scientists inside an International Organization for Standardization (ISO) 20 container—about 15 m^2 in size. In the project, the space is multifunctional and convertible; the different areas (working station, kitchen, and lounge) are mostly open and common, but guarantee privacy when convenient (Cenini et al. 2015).

FIGURE 16.9 ExoLab container for mission simulation at ESA-ESTEC. (Copyright Schlacht 2014.)

In May 2015, the ExoLab was structured and equipped as a technological mock-up to perform a space mission simulation. A team of nine members was invited by the ILEWG to address specific tasks as part of the safety simulation in order to verify how persons from different humanities and technical fields could make both cultural and technical contributions.

The crew had a classical task and hierarchy structure, but consisted of members from different humanities and scientific fields, divided between

- Remote support: Campaign director, commander, mission support
- ExoLab and ExoHab: Executive officer, crew engineer, health and safety officer, crew biologist
- ATV observatory: Crew astronomy specialist, crew scientist

Appropriate procedures are one of the most important things to create the feeling of simulation and make the results reliable. The procedure used referred to a basic space mission configuration.

FIGURE 16.10 ExoLab EVA communication check. (Copyright Schlacht 2014.)

Ordinary equipment was used to simulate professional equipment for extreme environments in order to perform the simulation at this first stage and learn and understand which equipment development would need to have priority in the next step of the project.

During the simulation, the crew performed research on life-forms living on rocks during EVAs, while the crew astronomer and the biologist worked in their fields of research, also getting inspirations for cultural applications. During the EVA, a communication breakdown was planned and two astronauts in EVAs performed a safety emergency procedure, while the crew biologist and the crew health and safety officer were left alone, each in one of the modules, to try and reconnect the communication. After the communication breakdown with ExoLab, the crew decided to get in contact with ExoHab. The crew member in ExoHab communicated to them the way to reach the ExoHab module, while the member in ExoLab was left alone with no communication connection. The crew members left alone experienced psychological reactions related to the feeling of isolation.

The complete EVA took about 60 min, and the ExoLab crew member left alone experienced isolation.

TABLE 16.2
Problems and Solutions Voted as Most Important and Discussed by the Crew during the ExoLab Mission (May 2015)

Problem	Problem	Solution	Field	Crew Vote
Instrument	Communication	Dedicated equipment	Operational—EVA/IVA	3/4
	Nothing was working in ExoLab		Operational—IVA	1/4
	Could not use trackpad with gloves		Operational—EVA	2/4
	During the day, the UV instrument had no darkness setting to do proper work and identify the right sample			
Panic	I got bored and panicked because of the boredom	Social care	Socio-cultural and psychological—IVA	2/4
	Panic; no equipment was working; I focused on sensory perception; I was scared and panicked; I tried to calm down by remembering past socio-cultural experiences from my life			

The simulation was performed successfully; each task was addressed appropriately.

After the EVA, the simulation concluded with a debriefing, performed in accordance with the habitability debriefing procedure described above, which holistically considers all human factors involved in the mission to learn how to improve safety and performance in the mission. The debriefing results are reported here anonymously and divided according to the factors used in the procedure (Table 16.2 and Figure 16.11).

FIGURE 16.11 ExoLab isolated during communication breakdown. (Copyright Schlacht 2014.)

1. Find problems and solutions: Socio-cultural, psychological, operational, environmental, and physiological aspects were investigated. Operational aspects emerged as the most frequently discussed problem; communication, in particular, was the key problem. Other problems were the breakdown of the equipment, the difficulties of using the trackpad with gloves, and using the ultraviolet (UV) instrument with daylight for sampling. Also, the cold emerged as a key problem related to physical and environmental factors. Boredom and panic emerged as socio-cultural and psychological problems.
2. Propose implementation recommendations to increase the overall system performance: Improvement of social care emerged as a keyword. Moreover, the development of dedicated equipment for communication technology, sampling technology, and gloves was suggested.
3. Also, successful achievements were discussed by the crew. The crew recorded these as short descriptions of positive personal experiences related mostly to psychological factors. Some examples include performing the sampling successfully, learning how to handle the feeling of isolation, learning to avoid boredom, experiencing a slow perception of time, sharing hands with the others when using instruments, and having an interesting experience with regard to waiting time.

Finally, a comparison between the scenarios was discussed. The aim was to discover the applicability and use of simulation in disaster contexts, such as the Fukushima radioactive scenario on Earth.

The crew had different comments about this. For example, they said both are hostile environments; however, there is a different psychological approach: in a radioactive environment on Earth, performing a mission is not something one wishes to do, while in space it is (Figure 16.12).

FIGURE 16.12 ExoLab communication breakdown during EVA. In the image, the gloves are removed to interact with the instrument; dedicated instruments are needed to perform a safe and successful mission. (Copyright Schlacht 2014.)

16.4.3 V-ERAS

Another scenario used to test safety and performance in relation to procedures, equipment, mission structure, and system is a simulation in virtual reality. In order to effectively test such a particular extreme environment, equipment needs to be developed to properly simulate the effect of specific factors, such as the different gravities or the absence of oxygen during EVA. In this case, a simulation realized by the Italian Mars Society is presented; specifically, the V-ERAS mission carried out in December 2014 in Italy is used as a case study. The virtual simulation is composed of a complex infrastructure and team structure (Figures 16.13 and 16.14).

The infrastructure is mainly based on four virtual stations characterized by the following key elements:

- Immersive virtual simulations on the Blender Game Engine (BGE) with three-dimensional (3D) virtual reality headset (Oculus Rift).
- Full-body tracking via a Kinect device.
- Main component: Four motivity omnidirectional treadmills (also called stations), which are specific structures where the user can visualize and interact with the virtual environment and which with a modified version of Motivity called Motigravity, also simulate the difference in gravity. These stations are linked via dedicated multiplayer support capable of synchronizing the events happening at the four simulation nodes.

FIGURE 16.13 Motivity V-ERAS. (Copyright Schlacht 2014.)

FIGURE 16.14 V-ERAS astronaut avatar on the Martian surface. (Copyright Schlacht 2014.)

- Mumble voice chat software is used to ensure the overall voice communication infrastructure.

The people involved are assigned specific roles and tasks:

- The team is composed of a mission director, science officer, technical support team, outreach communication team (Earth-based), and the crew that is performing the mission simulation (Mars-based).
- The crew is composed of a commander, executive officer, crew engineer, and a health and safety officer.
- The team supports the crew regarding the performance of the following experiments: habitat design and station design review, communication test, health monitoring, simulation of telemedical support session, ATV vehicle review, EVA missions review, simulating Martian reduced gravity (motigravity omnidirectional treadmill), test of the analog space suit during the simulation, human performance in teleoperation, and human factors analysis.
- The mission director is responsible for the overall mission operation, coordinating all necessary actions with the team. As far as we know, this virtual mission simulation was carried out for the first time with this configuration of equipment and experiments, developed specifically to achieve the most reliable conditions to simulate the main factors related to a Mars mission, from the difference in gravity to the difficulties in performing activities during EVA.

To test safety and performance using the IDP approach, the habitability debriefing was applied both in the virtual reality context (in intravehicular activity [IVA] and EVA conditions) and in the real context outside. The crew debriefing allowed learning from the crew how to improve the overall safety, performance, and comfort of the mission. Regarding the results obtained during the Italian Mars Society mission, four members of the crew with international and mixed-gender identity were tracked in virtual reality and were able to interact through an avatar with different field tasks on the Martian surface. The human factors discipline was integrated and evaluated during the simulation to find problems and solutions, as well as to propose implementation recommendations to increase the overall system performance, as described here:

1. Find problems and solutions: Socio-cultural, psychological, operational, environmental, and physiological aspects were investigated. Operational aspects emerged as the most frequently discussed problem; in particular, *motigravity* was the most frequently recurring word associated with *uncomfortable*. The main problems and solutions referred to increasing the quality of
   a. The system (test the system before the mission and increase the number of team members)
   b. The tasks (increase the margin among tasks to avoid overload; ensure free time for the crew, in particular after dinner, and physical training)
   c. The equipment (increase the comfort of motivity and the quality of the navigation)
2. Propose implementation recommendations to increase the overall system performance: It was proposed to implement the system for different user typologies and anthropometrics, tracking users with the anthropometrics of a 2-year-old child, using an extremely small human size to verify the performance of the system in abnormal situations; to implement the interior design and interface with movement data from tests in Martian gravity; and finally, to provide the possibility of interaction among crew members in VR (virtual reality). Social aspects did not emerge as a problem; however, late work and short periods of free time led to dissatisfaction, which was not approached by the team. In conclusion, it was verified again (as in the MDRS mission) that safety is strictly correlated with performance and comfort (Figure 16.15).

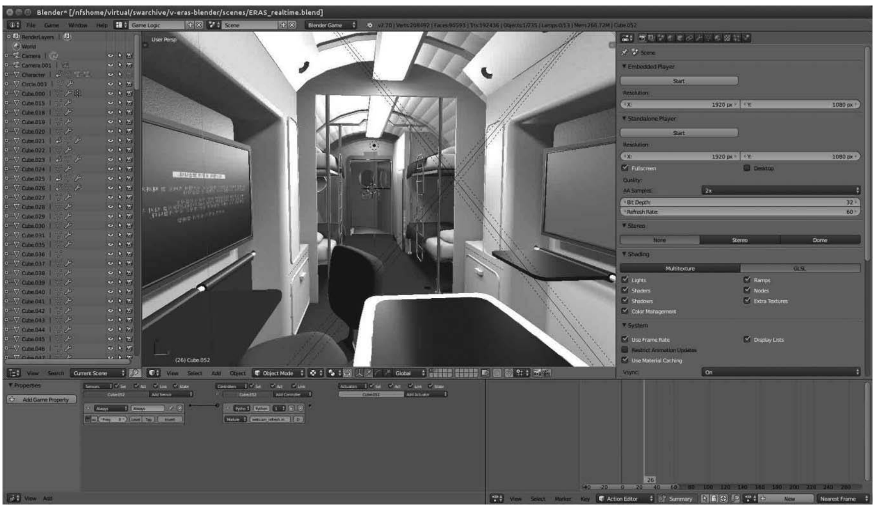

FIGURE 16.15 Interior of the V-ERAS Martian space station. (Copyright Schlacht 2014.)

16.5 SAFETY FROM SPACE TO EARTH

To support innovation in safety procedures for extreme, dangerous, and isolated environments, research related to the space environment has been presented here. Space was selected as the most extreme environmental condition that incorporates all the factors that characterize other extreme environments. For this reason, space missions can be used as a source for learning how to increase safety and improve user–system interaction in other extreme contexts on Earth. The transfer of research and design solutions from space can be valuable in terms of addressing problems faced in extreme environments, as well as in providing the base setting for transferring solutions to practical problems, both for today and for the future.

This chapter can be used to inspire specialists to use the space missions described in the scenarios as a model for realizing possible safety procedure implementations in all life-threatening, isolated, and extreme contexts. Although these environments are quite different, they share many of the problems regarding the support of human life in them. For example, considering the context of hospitals, the architecture needs to be user-centered in order to create an environment where it is enjoyable to spend time. As mentioned in the abstract of the International Conference Cluster in Design of Health Facilities, “The design of healthcare facilities requires a sensitive approach to minimise the sense of alienation and offer a welcoming and comfortable place for people for improving health through healing environments. Nowadays, architectures for health are suffering not only from a lack of resources but also from a whole vision of hospital’s needs. Therefore, the attention to topics like safety, environmental sustainability, comfort and well-being, requires a typological, structural and managerial re-organization of the design process: for this reason, it is important to involve hospital planners and design teams for boosting innovative design strategies through highly experienced professionals and stimulating debate on these issues” (SItI 2015), and maybe get inspired by space missions.

Space is a domain characterized by a huge amount of complexity in terms of technical details as well as operational processes. The interconnections among the agents involved in this complex system add to the risk-proneness. The user astronauts, who are the social components of these sociotechnical systems, play a vital role in overall safety. Thus, the right operator or astronaut must be selected for this job, and training is needed to provide the necessary skills to ensure smooth as well as safe operation in these contexts.

It has been verified that training in an immersive environment allows increasing the safety of the equipment and the operator during an accident scenario. As described here with three different simulation approaches, it has been verified both in virtual reality and in analog environment simulations that safety is strictly correlated with performance and comfort, involving the optimization of human factors. This is because in the space context, the user is involved in an extremely dangerous context during a period of several months, which includes not only working time, but also living time (Schlacht 2012). This is why it is important to have an environment that can simulate all the factors that may impact safety, performance, and comfort. With the holistic approach, socio-cultural, psychological, operational, environmental, and physiological factors are investigated together by all the crew members to show the interconnections related to safety, performance, and comfort. To understand why all these human factors are so important for the overall safety in extreme contexts, one can easily imagine that in a space mission, the user cannot be replaced (just like a hivernaut on Antarctica, an astronaut cannot easily return and be replaced either). This is the reason why he needs to be supported with a holistic perspective in order to keep up a high level of performance and reliability. However, with respect to isolated environments such as space or Antarctica, the overall risk involved in a dangerous scenario on Earth may be much higher, as the consequences for the surrounding population and the environment of a production site, for example, could be considerable (e.g., in the case of an explosion at a chemical plant). The above-mentioned factors need to be predicted and recognized in time, which is why it is rather important to adopt a holistic approach, in particular during measures aimed at prevention, such as operator training. Finally, in order to prevent accidents in particularly dangerous environments, simulation and training in scenarios that are as similar as possible to the real condition can be accomplished in an analog or 3D immersive virtual environment.

16.6 CONCLUSIONS AND FURTHER DEVELOPMENTS

In conclusion, we can summarize that in all contexts presented in this chapter, the users played a vital role regarding overall safety and need to be approached holistically. Indeed, in space as on Earth, the most important variable is the user, the operator, or better still, the "unpredictable human." This is why whenever there is any human interaction, it is more important to test the elements not only in isolation, but also holistically, as an overall system simulation, in order to predict possible user interactions. Especially during an extended system simulation, the variables interact with each other, which leads to much more reliable results regarding the increase of user and system safety. To repeat the words of Aristotle, "The whole is greater than the sum of its parts."

Further investigation is needed regarding the application of

- IDP as a methodology for developing projects based on human factors, user-centered design, and a holistic approach
- A sustainable system with the benefit of technical system autonomy, as well as user experience and reliability
- Overall human–machine system simulations and IDP-based debriefings
- Crossover benefits to increase safety in extreme contexts both on Earth and in space

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