Acta Astronautica 139 (2017) 306–312

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Integrating spaceflight human system risk research

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ARTICLE INFO

Keywords:
Risk
Research management
Integration
Crew health

ABSTRACT

NASA is working to increase the likelihood of exploration mission success and to maintain crew health, both during exploration missions and long term after return to Earth. To manage the risks in achieving these goals, a system modelled after a Continuous Risk Management framework is in place. "Human System Risks" (Risks) have been identified, and 32 are currently being actively addressed by NASA's Human Research Program (HRP). Research plans for each of HRP's Risks have been developed and are being executed. Inter-disciplinary ties between the research efforts supporting each Risk have been identified; however, efforts to identify and benefit from these connections have been mostly ad hoc. There is growing recognition that solutions developed to address the full set of Risks covering medical, physiological, behavioural, vehicle, and organizational aspects of exploration missions must be integrated across Risks and disciplines. This paper discusses how a framework of factors influencing human health and performance in space is being applied as the backbone for bringing together sometimes disparate information relevant to the individual Risks. The resulting interrelated information enables identification and visualization of connections between Risks and research efforts in a systematic and standardized manner. This paper also discusses the applications of the visualizations and insights into research planning, solicitation, and decision-making processes.

1. Background

1.1. Context

NASA is committed to mitigating the in-mission and long-term health and performance risks of astronauts to enable safe, reliable, and productive space exploration missions. The NASA Human System Risk Board (HSRB) provides the forum for a process that manages the overall mitigation strategies for these human system risks (called "Risks" in this community) based on the Continuous Risk Management (CRM) framework and is overseen by Risk stakeholders within the agency from medical, operations, and research areas. The HSRB maintains an official record for each Risk's relevant evidence base, the mission-specific Risk ratings and their drivers, contributing factors, available countermeasures, metrics, and notable deliverables.

Within the set of Risks managed by the HSRB, many have been identified as requiring research as a significant part of their mitigation and have been assigned to the Human Research Program (HRP) to conduct necessary work. At this time, the HRP is implementing activities for characterizing and providing countermeasures and technologies to address 32 Risks in its research portfolio. Each of these Risks has a research plan that outlines the knowledge gaps that specific tasks are aimed to support as well as the schedule for their execution. Shared gaps and tasks between the Risks are noted in these research plans and are documented in the Human Research Roadmap (HRR) [1]. The HRR also provides general descriptions and context for the Risks.

Common information across the Risks is reflected in the HSRB Risk records and acknowledged in the HRP research plans. However, a systematic approach to better understand the linkages across Risks to form a basis for better integration of work and resources has not been followed. This paper outlines a new approach to facilitate the integration of Risk research and mitigation strategies to support HRP's goals.

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http://dx.doi.org/10.1016/j.actaastro.2017.07.017
Received 14 January 2017; Received in revised form 22 May 2017; Accepted 10 July 2017
Available online 13 July 2017

Acronyms/abbreviations

CFM	Contributing Factor Map
CRM	Continuous Risk Management
ExMC	Exploration Medical Capabilities Element
EVA	Extravehicular Activity
HHC	Human Health and Countermeasures Element
HRP	Human Research Program
HRR	Human Research Roadmap
HSRB	Human System Risk Board
OIG	Office of the Inspector General
NASA	National Aeronautics and Space Administration

1.2. Motivation

Recent reports from groups that reviewed aspects of NASA's plans for reducing crew health and performance risks provide two examples of external motivation. The Office of the Inspector General (OIG) reported in 2015 (emphasis added) [2]:

> *"NASA's management of crew health risks could benefit from increased efforts to integrate expertise from all related disciplines. While many life science specialists attempt to utilize the range of available expertise both inside and outside the Agency, NASA lacks a clear path for maximizing expertise and data at both the organizational and Agency level. For example, NASA has no formalized requirements for integrating human health and research among life sciences subject matter experts nor does it maintain a centralized point of coordination to* ***identify key integration points for human health****... The lack of a coordinated, integrated, and strategic approach may result in more time consuming and costly efforts to develop countermeasures to the numerous human health and performance risks associated with deep space missions."*

Similarly, the Health and Medicine Division of the National Academies of Sciences, Engineering, and Medicine reviewed Evidence Reports that are produced to capture the state of knowledge of the crew health and performance risks. The 2014 report states (emphasis added) [3]:

> *"The reports... struggle with* ***establishing the connections and interactions among risks that are related****, but a bit more tangential (e.g., altered immune response and inadequate nutrition)."*

There is growing recognition within the crew health and performance community that developing solutions to the challenges posed by human spaceflight exploration missions requires crossing discipline boundaries. The HSRB has recently expressed a desire to better integrate the management of the Risks. HRP is recognizing the need to leverage connections to better identify and manage work to more efficiently use constrained research resources across disciplines and support innovative solution development.

In any system development process, *interfaces*, whether they are conceptual, technical, or managerial, are where many challenges appear. The HRP currently has no systematic approach that pulls on the available Risk information to identify intrinsic interfaces that are embedded in the data. At this time, efforts to identify these have been mostly ad hoc. The efforts are therefore susceptible to overlooking additional linkages between Risks that have the potential to reveal new areas of research collaboration addressing multiple Risks. Thus, HRP has less ability to ensure that the most impactful work across disciplines, given resource constraints will be addressed.

In spaceflight systems engineering, discipline and subsystem (e.g., structures, avionics, power, and propulsion) scopes are well defined in a common conceptual model. This enables the management of interfaces throughout the development process, which supports the development of an integrated system. The work discussed in this paper is one approach to addressing this need and can be an early step to improve the scope and interface definitions of the Risks to promote integrated system solution development.

1.3. Purpose and scope

The specific purpose of this initial exercise was to demonstrate techniques to systematically identify, organize, and manage interfaces among Risks. The scope was intentionally kept limited for this initial effort to determine if future work would be valuable. Input data were limited to existing information, favouring rapid proof-of-concept ideas and results over a more involved project scope and timeline. With this philosophy in mind, existing HSRB Risk records were used as the source of information to characterize each Risk's contributing factors, mitigations, and metrics, and the HRR was used to determine the scope of research work for the Risk. Because the baselined Risk records available at that time were created by different experts and were the first versions created as the risk process was being established, the contents in each were at varying levels of completeness. An analysis of the completeness of the information available in this exercise was not included; however, observations to support any future systematic completeness analysis were noted.

2. Approach

The team defined the following four steps to demonstrate the analysis technique, the goal of which was to identify potential areas of integration between HRP risks:

1) Normalize Risk record content using a common framework of terminology.

This step allowed content in the Risk records provided by experts from different disciplines to be captured in the same conceptual model. The outcome provided the combined data set crossing all available Risk records.

2) Identify Risk interfaces.

In this step, the team defined types of interfaces of interest and then applied the combined data from the Risk records to identify related Risks.

3) Compare to planned research.

Next, a first-pass evaluation of the integration status of Risks that were identified as related in Step 2 was performed. HRP's HRR shows the research plans for each of its Risks, and research activities, called "Tasks", are in place to accomplish those plans. Tasks can be linked to more than one Risk, allowing discipline experts focused on a particular Task to indicate when a Task's work also supports other Risks. The determination of these links has previously been made in an ad hoc manner, but provided the team with one indication of the current state of awareness of conceptual interfaces. The team compared which Risks shared Tasks in the HRR to the set of relationships identified in Step 2 to identify potential collaboration areas.

4) Visualize options for collaborations and their status.

Finally, visualizations were created to support communication of the integration options and their status. These visualizations created the potential for tracking progress of integration in the future.

3. Methods

This section describes the activities undertaken for each of the four