Use of Cautions and Warnings within International Space Station Procedures: When Too Much Information Becomes Risky

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ABSTRACT

Working on the International Space Station (ISS) has uncovered several challenges in the prevention of human error and desensitization to hazard advisories. Although human centered design strives to eliminate accidents, there are still many unknowns in long term space habitation. Specifically, during the last fourteen ISS Expeditions, the crew has indicated that cautions and warnings (C&Ws) were used inappropriately within procedures. Human factors and safety personnel reviewed all comments made during ISS debriefs and a sample set of procedures. Findings included: no human factors input in procedure development, inconsistencies in procedure development, unclear C&W standards, and overuse and misuse of C&Ws throughout procedures. A usability evaluation was conducted to assess C&W intuitiveness for a specific set of C&W's: Touch Temperature, Shock, Electrostatic Discharge, Rack Rotation, and Foreign Object Debris. This work focuses on the review findings, usability evaluation results, recommendations to NASA, final implementation and application to industry.

INTRODUCTION

To successfully carry out space exploration goals on the International Space Station (ISS), safe-guards must be in place to protect the crew against safety risks that may be incurred during exploration operations. For all tasks conducted by the ISS crews, there are required operational procedures. NASA standards document, specifically Space Station Program (SSP) 50253 Operations Data File Standards Document, directs that all "necessary" hazard information be provided to the crew within these procedures. When developing procedures, the incorporation of clear hazard information is critical for safe-guarding the human and effectively conveying hazard information (Friedman, 1988). Research conducted on the effectiveness of hazard information, specifically what conditions must always be present for hazard information to be conveyed successfully. It is often difficult to determine exactly how much and what level of hazard information is necessary to afford safe practices, while preventing informational overload that would cause user desensitization issues, and therefore additional safety risks. These parameters are often dynamic and can not be universally applied, but often depend on the background and familiarity of your users and their perception of risk (Ortiz et al., 2000). It is also dependent upon frequency and the perceived level of validity of a hazard communication (Maltz et al., 2001). The frequency and perceived validity also effect the users level of risk perception and indirectly contributes to desensitization.

However, there have been clear findings relating to what content should be present to adequately convey a hazard situation and the required mitigation. Specifically any hazard communication should include three main elements: the signal word to alert there is a hazard, the consequences of the hazard, and instructions to avoid the hazard (Rogers et al., 2000). The signal word must convey the presence of a hazard and indirectly the gravity of risk involved, for example "Caution" or "Warning". After the signal word, consequences of not heeding the hazard must be listed. Instructions or steps to mitigate or avoid the hazard must also be communicated after the consequences of the hazard are stated (Rogers et al. 2000).

One of the methods NASA uses to provide hazard information within procedures is to provide a caution or warning (C&W) advisory block before the step in the procedure where the hazard presents itself. The primary purpose for using C&W advisory blocks within procedures is to protect the ISS crew and the hardware from potentially unsafe conditions or incidents. NASA defines how Cautions and Warnings are to be used within procedures differently from general Industry. Specifically, Cautions are only used to advise for hardware damage and Warnings are only used to advise for crew harm. Although the rationale behind using these C&Ws is well-founded, in practice the methods that have been used to implement these safe-guards have not reached the desired intent. The fourteen ISS Expedition crews, to-date, have returned consistently citing misuse of C&W information within procedures as problematic and responsible for creating an environment conducive to desensitization to C&Ws.

One primary resource for the crew feedback is the ISS space exploration data obtained from the crew debriefs. Data is collected from every Expedition crew during the post flight debrief process. Each debrief is attended by a member of the human factors team and the collected data are entered into a database, which is used to document "experience" statements made by the crewmembers. This comprehensive database is used to track and capture successes and issues during the ISS program. A number of comments have

focused on the misuse and abundance of C&Ws within procedures. Specifically, the crew has reported that having a C&W for every potential hazard is not necessary or practical. Many of the C&Ws used were felt to be intuitive and well understood by the crew, for example, scissors are sharp. In addition, the overall excessive use of C&Ws has contributed to the desensitization of the crew to C&Ws. Due to this desensitization, there have been several instances where the crew has not read important C&W advisory block messages. This consistent crew feedback highlighted the need for further investigation and research into the root causes of this issue to help prevent future incidents of human error.

METHOD

Standard operations at NASA include many disciplines working together early in the design process to develop good requirements and optimal hardware interfaces for humans functioning in space. The human factors team primarily interfaces with hardware developers, safety personnel, program management, mission operations personnel, and astronaut crew representatives to achieve the best designs possible and assist with issue resolution. To investigate the root cause of the crew concerns, a Caution and Warning Advisory Group (CWAG), with representatives from human factors, safety, astronaut office, and procedure developers was formed. The CWAG sought to evaluate and research the issue, develop a risk mitigation plan, and present it to NASA.

The risk mitigation plan was developed in three phases. Phase one included a review of Expedition crew debrief data regarding C&W use, applicable NASA procedure standards, and a sample set of ISS procedures. Phase two consisted of a review of industry practices and general literature on C&W use. Phase three included a usability evaluation to determine the "true" level intuitiveness of certain C&Ws.

Phase one consisted of the evaluation of all Expedition crew debrief data relating to C&W use in procedures. This experiential data, unique to NASA operations for long duration space flight, is collected at three different cyclical points in time during each mission: pre-flight, in-flight, and post-flight. Pre-flight is the time frame before a scheduled flight/mission during which many astronauts are asked to evaluate planned flight hardware during its development phase. During this time, the crew and human factors experts can evaluate features of the hardware for its usability, maintainability, and its effects on habitability. The crewmembers' evaluations are documented via verbal commentary, quantitative and qualitative questionnaires, photographs, and audio/video recordings.

Questionnaires are developed periodically (pre-flight, in-flight, and post-flight) to address specific concerns that arise
and to elicit knowledge from crewmembers about their operational on-orbit experience, personal preferences, and suggested improvements.

In-flight is the time frame when the Mission Control Center (MCC) and the Mission Evaluation Room (MER) provide on-console support for all functions and tasks carried out on-board, and provide problem resolutions for issues that the crew may have with systems or hardware on-orbit. Human factors experts are solicited to support issues that arise that may compromise the habitability, productivity, or performance of the crew. For example, human factors experts are consulted to determine the operational impacts to the crew for hardware anomalies, such as light failures.

Post-flight is the time frame when crew debriefs are conducted. For crews returning to Earth, a series of debriefs are held that provide an opportunity for various NASA discipline teams to address the mission/expedition issues and collect more detailed data for their subject area. Typically, at the end of each Expedition, the lessons learned are documented and made available to the NASA community for application to the next Expedition, and next space program. Post-flight data has been collected from U.S. astronauts living on Skylab, Mir, and the ISS. However, this work was based on data gathered from the ISS Expeditions, which encompasses information from 17 astronauts and 18 cosmonauts, to-date. The C&W data review was conducted by the human factors personnel, using the ISS crew comments database, to define what additional comments had been made regarding C&Ws through-out the ISS lifetime.

The crew comment review highlighted numerous issues with C&W usage, and based on this information the CWAG determined that a review of a sample set of procedures would also be necessary. The sample set of 100 procedures were chosen based on crew comments made during the debriefing process. The comments emphasized specific types of procedures (i.e. maintenance, medical operations, and robotics procedures) that the crew felt continually exhibited inappropriate usage of C&Ws. The procedures were reviewed based on the following criteria: number of C&Ws used within each procedure, total number of procedure pages reviewed, identification and frequency of repeated C&Ws throughout the sample set, comparison of the number of total C&Ws used to the total number of procedure pages, and compare C&W content to the current standards. This review was used to define what types of C&Ws were being used, the frequency of use across the sample and to establish an understanding of how C&Ws were implemented. Because, procedure writers are directed to follow established standards for procedure content development, including C&W content, NASA standards document SSP 50253 was reviewed in parallel and compared against the procedure sample set. The standards were evaluated to help determine if the implementation of C&Ws within the procedure sample set followed the standards, and if this could be a contributor to the desensitization comments.

Phase two consisted of a review of industry practices and general literature on C&W usage. The review evaluated areas in which the NASA standards could be improved. Phase three consisted of a usability evaluation focused on determining whether the five most commonly cited C&Ws, identified in the sample procedure review, were truly "common" and "intuitive" to the crew and could be

considered for removal from the procedures. Twenty-four crewmembers were asked to evaluate an ISS procedure that did not contain a specific set of C&W advisory blocks. The set consisted of the five most commonly identified C&W advisory blocks from the procedure review (Rack Rotation, Foreign Object Debris, Touch Temperature, Shock, and Electrostatic Discharge). The crew was provided a list of these C&Ws and was asked to indicate which steps in the procedure should have contained one of these C&Ws or referenced a hazard. The success criteria for percent correctly identified was set at 70% for each C&W type.

RESULTS/DISCUSSION

Phase 1 findings led to the identification of several additional crew concerns. These concerns included: C&Ws were not used "conservatively" throughout the procedures, C&Ws were used generically for any danger level, excessive C&W usage causing the importance of C&Ws to become lost, the same C&Ws were repeated numerous times throughout the same procedure, and many of the C&Ws were considered intuitive, not of a critical nature, and tended to be ignored.

The procedure and NASA SSP 50253 standards review yielded the following findings: There was variation in how procedures were written. Specifically, there were multiple procedure writers and procedure reviewers, there was more than one document that provided procedure writing standards, and the standards were not written clearly to afford consistent application of the standards across procedure writers. C&Ws were found to have been used incorrectly through-out many of the procedures that were reviewed, based on NASA standards and hazard literature findings. Particularly, C&Ws were not located in the correct place within the procedure, C&Ws were not clearly defined or communicated, and many were identified as procedure steps rather than C&Ws. Additionally, some of the examples within the standards documents did not comply with the standards.

The procedure review also identified five C&Ws that were used frequently, and considered common, throughout all of the procedures. These included C&Ws for: Rack Rotation, Foreign Object Debris, Touch Temperature, Shock, and Electrostatic Discharge. In addition, to the five common C&Ws, many non-critical hazards were noted; i.e. pinch points. This assessment emphasized the need to improve on the current NASA SSP 50253 standards and determine if the five most common C&Ws could truly be considered intuitive to eliminate the need for a C&W advisory block within the procedure.

Phase two findings, based on the industry and literature review, indicated that there are two primary variables of effective vs. ineffective warnings (Warning and Personal) and three main elements (Signal, Consequence, and Instruction) needed when communicating cautions and warnings (Rogers et al., 2000). Warning variables consider factors such as over-use, length, the depth of content, credibility of the source, font size, color, and text vs. symbols or pictures. Personal variables take into account factors such as over-exposure, comprehension, familiarity/training, perception/belief, and cost of compliance, risk taking personality, gender, age, and workload. In addition, the three primary elements needed for effective C&Ws are *Signal word*, the word that conveys the gravity of the risk (Caution or Warning), *Consequences*, what is likely to happen if the caution or warning is not heeded, and *Instructions*, appropriate behavior required to reduce/mitigate the hazard (Rogers et al., 2000).

The review of the crew comments, the sample set of procedures, the NASA standards, and literature emphasized that the warning and personal variables were not considered in development of the standards and consequently the procedures. Specifically, components included: overuse, depth of content, over-exposure, training, risk taking personality, age, and workload. It was also found that the three elements needed to create an effective warning were not clearly outlined within the NASA SSP 50253 standards to facilitate effective implementation and use of C&Ws by the procedure developers. Therefore, many C&Ws within the procedures were found to be incomplete in providing the necessary hazard information to the crew. Specifically, there was always a signal word present, i.e. "Caution" or "Warning", but the consequence of an action and the appropriate instructions to avoid the hazard were not always components that were present in the C&W advisory blocks.

These results led to the update of NASA SSP 50253 standards document to provide better and more accurate standards and examples of acceptable methods of C&W implementation. The updates also clarified all descriptive language regarding C&W development and implementation within procedures.

Phase three included the usability evaluation, the findings helped determine that the five commonly used C&Ws were in fact "common" and "intuitive" to the crew, based on the percentage correctly identified for each common C&W (See Table 1). Although the usability evaluation findings were critical in determining no a need for these particular C&Ws in the specified cases, additional information and variables were considered. The reality of long duration space flight is that the crew has more hazard information cues available to them than just C&W advisory blocks within procedures. Cues include: information in the form of procedure steps, C&W labels placed on the hardware, and general situational awareness of the living environment.

Based on these factors, the SSP 50253 standards document was updated to no longer require C&W advisory blocks for: Rack Rotation, Foreign Object Debris (FOD), and Electrostatic Discharge (ESD). *****Touch Temperature will no longer be represented by a C&W advisory block as long as there are mitigation steps within the procedure steps to avoid touch temperature hazards. *****It was determined that all Shock hazards above 32 volts and 3 amps would still require a warning block due to their catastrophic nature (See Table 1). The determination for touch temperature and shock to require caution and warning blocks for the above conditions, were due to general NASA operational safety regulations and constraints developed to protect a crewmember's life or

mission critical hardware (hardware required to preserve the crewmembers well being in space)) from catastrophic harm.

Hazard Concern	**% Correctly Identified**	**Recommendation**
Touch Temperature	100%	*****Remove only for specific case
Shock	70%	*****Remove only for specific case
Rack Inertia	96%	Remove
FOD	77%	Remove
ESD	100%	Remove
Overall	**88%**	

Table 1: For the five most commonly cited C&Ws within procedures, the table indicates the percent correctly identified by the crew and recommendations.

CONCLUSION

Collectively, these findings represent the root causes for crew comments regarding desensitization to cautions and warnings used within ISS procedures. In an effort to reduce user desensitization, increase hazard recognition and the likelihood of compliance to critical hazard information, the review, including literature findings and industry standards, and evaluation findings have been used to develop clearer NASA standards for caution and warning development and use. In addition, intuitive information, i.e. the five most commonly cited and low level hazards, will no longer be placed within C&W advisory blocks to preserve the importance of such advisories.

These findings are also directly applicable to industries or organizations that use any type of procedures to conduct daily tasks, train employees or users, or produce marketable products to the public that may pose safety risks during use. Successfully communicating hazard information to employees or consumers is critical in safe-guarding them against inherent risks that can easily be avoided. However, the method and amount of information presented, and the receiving audience, dictates how the information will need to be communicated. The method of communication will be different for every population and task situation. These variables should be evaluated when producing and conveying any type of hazard information to ensure successful reception and interpretation of the intended meaning of the hazard.

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