RELAAy – A Tool to Guide HSI Requirements

John M. Colombi, Ph.D.
Dept of Systems and Engineering Management
Air Force Institute of Technology
Wright-Patterson AFB, OH
john.colombi@afit.edu

Nicholas Hardman
Dept of Systems and Engineering Management
Air Force Institute of Technology
Wright-Patterson AFB, OH
john.colombi@afit.edu

This work was supported in part by the 711th Human Performance Wing/RH, US Air Force. The views expressed in this paper are those of the authors and do not reflect the official policy or position of the US Air Force

Abstract. Archives of Air Force mishap investigation reports provide a large data set of documented system failures. In this paper, we present a tool that analyzes human-related errors in these mishaps and quantitatively predicts focus areas for new system development. Even new systems have similarities, either in structure or function, to legacy systems. Knowing what design induced errors have plagued past human-machine interactions can guide new Human Systems Integration (HSI) requirements generation. This is accomplished using the Human Factors Analysis and Classification System (HFACS) as the underlying data. Our tool, with a novel method of using the entire mishap data set over the last five years is demonstrated through its application for a next generation unmanned aerial system (UAS). Lastly, the HFACS data is mapped to the domains of HSI for program office consumption.

Introduction

Within the Systems Engineering community, human systems integration (HSI) is the "interdisciplinary technical and management processes" ensuring human considerations get included during system development (Haskins, 2007). These considerations have a variety of taxonomies throughout the community, but generally reflect topics in manpower, personnel, training, human factors, safety, survivability, habitability, health and the environment. Other related labels may include ergonomics, occupational health, and human resources (Mueller, 2008; Narkevicius et al, 2008). Including the human in the systems engineering processes is critical given that it is typically humans which are ultimately responsible for the operation and maintenance of the systems created. Recent INCOSE efforts have emphasized HSI throughout the systems lifecycle and across the technical processes. These efforts have included active HSI Working Group activity, enhancements to the Systems Engineering Handbook, an HSI themed issue of INSIGHT magazine, as well as the Human Systems theme of the 2009 INCOSE Symposium.

This paper continue the INCOSE momentum by providing results on a proposed HSI tool, called Requirements Elicitation through Legacy Aircraft Accident Analysis, or RELAAy. It makes use of historical aviation mishap data. Human error is now deemed the primary risk to flight safety. Studies report that between 60-75% of all aircraft accidents involve human-related actions (Shappell et al, 2007; Dekker, 2006; Fiorino, 2006; Li, 2006; Shappell and Wiegmann, 2003a).

This includes not just the operators in direct aircraft control, but also the humans that, as part of the overall system, perform training, maintenance, and supervision.

Background – Human Error Analysis

Human error has been a highly studied area for decades. At a philosophical level, some deny that true human error really exists, and others believe that it is the root cause of all great tragedies (Dekker, 2004). At an operational level, researchers have greatly improved our understanding of the phenomena. We now have much more sophisticated human error models and error taxonomies regarding the cognitive, perceptual, physiological, and, more recently, organizational aspects. Researchers now advocate that a hazard becomes an accident through the ill-fated alignment of certain latent conditions within the layers of protection in place to prevent such accidents (Reason, 1990). While active errors have immediate impact on the system, latent conditions are removed in time and space from the actual event. Figure 1 includes a graphical representation of this accident causation model, commonly called the “Reason Model” after Dr. James Reason, or the “Swiss cheese model.” Reason advocates that a focus on these latent conditions holds the most promise for safety improvement (Reason, 1997).

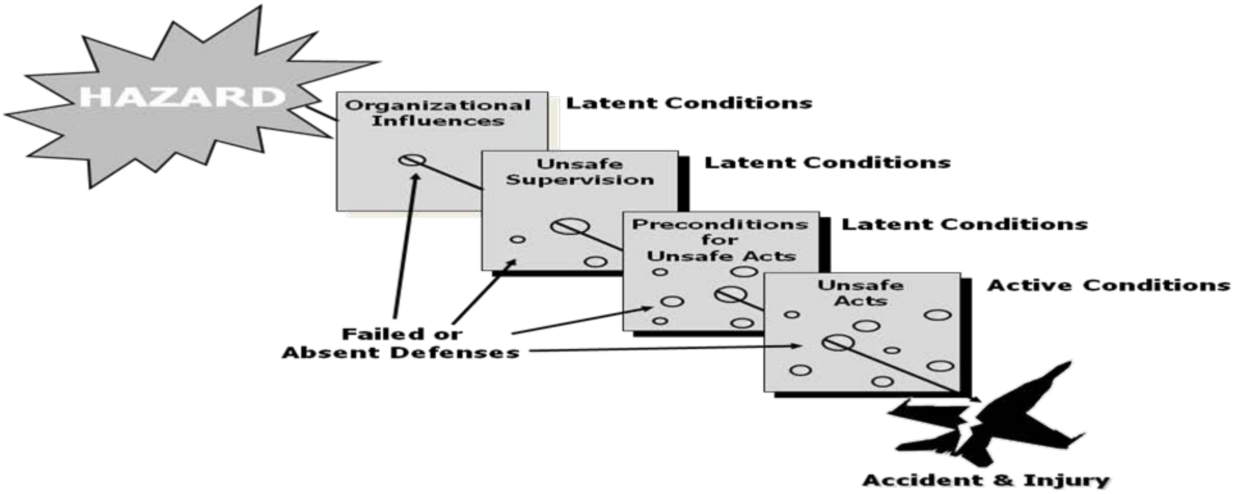


Figure 1. Accident Causation Model (Reason, 1997)

Investigators in all industries have been motivated by this accident causation model to take a deeper look at human error and its causal relationship with accidents. In aviation, this has spawned a theoretically-derived human error framework called the Human Factors Analysis and Classification System (HFACS). Since fiscal year (FY) 2004 the Department of Defense (DoD) safety community has implemented an HFACS-based taxonomy for use in its aviation accident investigation process. As Figure 3 shows, the DoD-HFACS identifies four tiers of active failures and latent conditions: Acts, Preconditions, Supervision, and Organization. These are each decomposed into categories and then specific sub-codes (AFSC, 2007). For descriptions of all 147 DoD-HFACS codes, refer to Hardman and Colombi (2009).

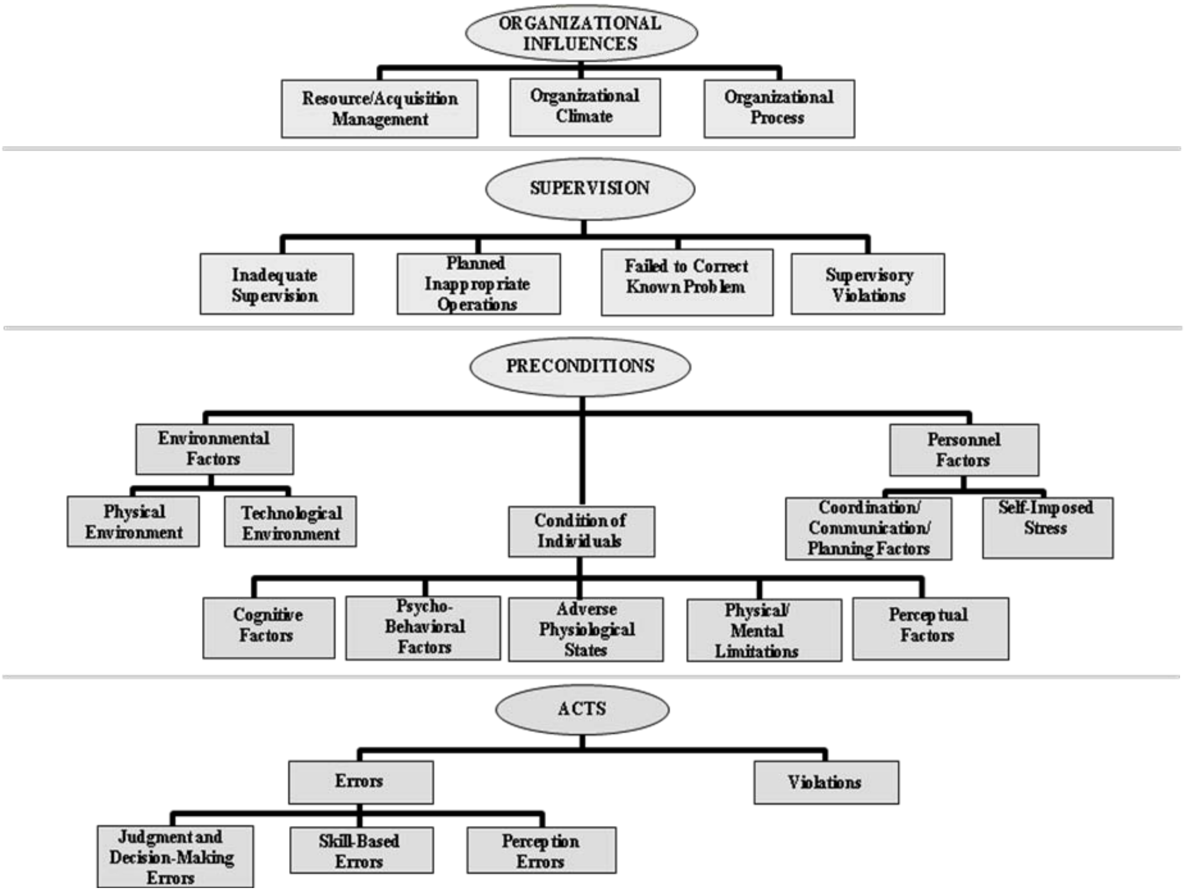


Figure 2. Human Factors Analysis & Classification System (Wiegmann & Shappell, 2001)

HFACS has allowed for a deeper level of accident investigation. Instead of "human error" being seen as the root cause, it is now viewed as the beginning of an investigation into the human-machine interaction breakdown. HFACS allows investigators to characterize a mishap, as in the Reason model, as a function of latent failures. It begins with the active failures and then looks for latent conditions and latent factors in the environment. HFACS has been used to study mishaps across all branches of the military (Thompson et al, 2005), in commercial aviation (Li, 2006;Wiegmann & Shappell, 2001), and in multiple recent UAV mishap studies.

Design-induced error is a big concern of airworthiness authorities, especially in new, highly automated aircraft. Accident investigations of most major accidents have traced contributing factors to latent failures in system design (Salvendy, 2006). This led the Federal Aviation Administration (FAA) to decide that new aircraft designs should be evaluated for susceptibility to design-induced errors (Stanton et al, 2006). Attempts at doing this empirically are costly and must be done late in system development when the design decisions cannot be undone without great expense. Usability inspection methods, such as cognitive walkthrough, are based on human cognition models and attempt to address design problems earlier and cheaper. Other approaches for the early identification of design induced errors include the Systematic Human Error Reduction and Prediction Approach (SHERPA), Human Error Hazard and Operability study (HAZOP), and Human Error In Systems Tool (HEIST). In general, these are used in conjunction with other human factors methods, such as a hierarchical task analysis, to examine what might go wrong based on the type of activity. Many organizations with mature reliability engineering programs use Failure Modes, Effects, and Criticality Analysis (FMECA) processes.

Most of these error models tend to be theoretical and academic. Practitioners have resorted to developing error-management programs based on intuition rather than on theory and empirical data. In fact, Johnson (1999) states, “It is ironic that there has been so much research into human error analysis and yet so little attention has been paid to those who must apply the techniques.” He also notes a “lack of integration between contextual analysis and requirements analysis.” He cites a need for methodological support to help practicing engineers take contextual factors into account during design.

The tool and underlying method presented in this paper is intended to meet the needs of the practitioner involved in new system development. It describes how to perform requirements elicitation early in the design process by performing an empirical study of legacy system mishaps involving human error as a causal factor. This is similar to the failure analysis methods used by the designers of aircraft structure or propulsion systems. They have established that successful preventative actions are based on a correct understanding of causal factors (Wiegmann & Shappell, 2003b). The White House Commission on Aviation Safety and Security made a definitive conclusion that the incidents of mishaps caused by human error can be reduced by the effective sharing of safety data (White House, 1997). This conclusion was reinforced by the recent crash of a US Air Force transport aircraft when it was found that the same adverse human-machine interaction had been cited in the crash of a bomber aircraft two years prior (Roltsen, 2009).

Method of Requirements Elicitation

The proposed method involves a quantitative analysis of the significance of active and latent human component issues in similar contexts with similar systems to the system under development. Figure 3 shows a representation of the engineering process of investigating and preventing accidents that was first delineated in (Wiegmann & Shappell, 2003b). In the acquisition stage, a new system is developed. During this time, the system is also being inadvertently implanted with latent conditions for failure, whereby a hazard can manifest as a full blown accident in the fielded system. When an accident does occur, it is investigated following mature and objective techniques and procedures. The findings are then classified and stored in a structured database. For human error incidents, this classification makes use of HFACS. This supplies accident analyses efforts with useful and objective information, and forms the feedback to reduce accidents. Mitigation efforts seek to reduce the incidence of the same accidents in existing systems. Mitigation efforts alone are insufficient. Prevention efforts must improve so that current operational difficulties are addressed in new systems. To do this, methods must contribute to removing the discontinuity between users and designers.

This new method contributes to a more robust accident prevention feedback loop. It also systematically maps issues to the domains of interest in DoD acquisition. This directly relates the requirements development process to the empirical data of the safety community; making those conclusions more objective than would otherwise be possible. The method involves the following steps, as shown in Figure 4 and expanded further.

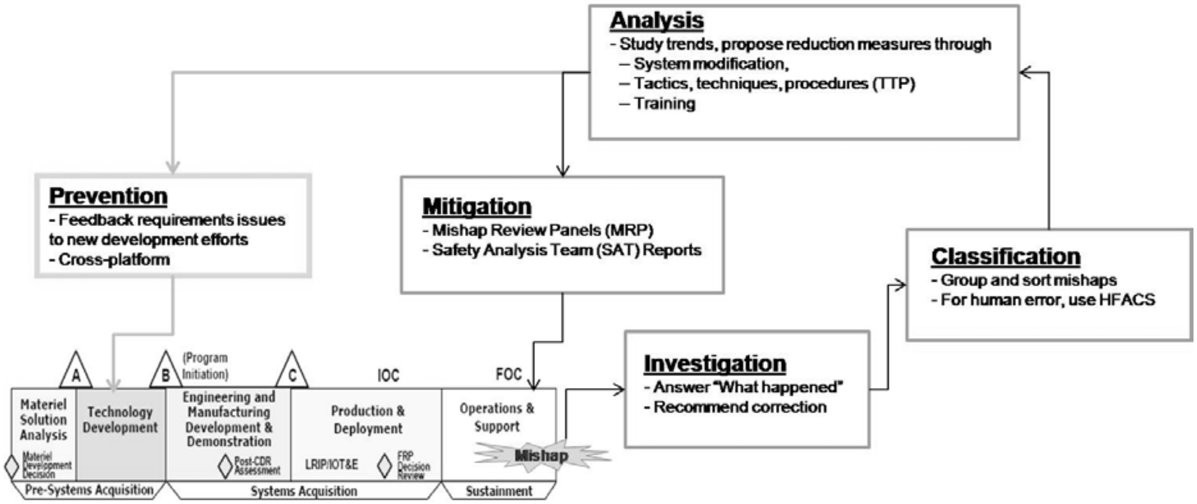


Figure 3. Engineering Process for Investigating and Preventing Accidents

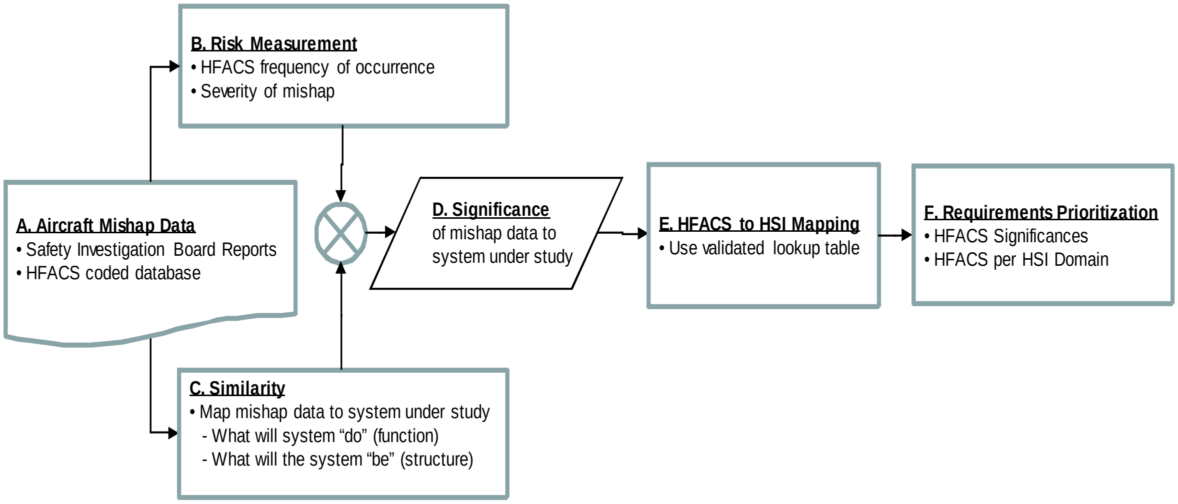


Figure 4. Process for Requirements Elicitation from Mishap Investigations

A. Data Acquisition

The first step is gathering the proper data. Each branch of the DoD, along with most NATO forces, has an independent safety organization responsible for accident investigation and reporting. In the US Air Force, it is the Air Force Safety Center (AFSC) whose Safety Investigation Board (SIB) process is guided by AF Instruction 91-20. As mentioned, the use of HFACS coding of human error is now mandated. These SIB reports have limited releasability. All recipients must demonstrate legitimate need of the data and sign a nondisclosure agreement. However, derived conclusions are releasable as long as the data is presented in aggregate (e.g. no individually identifying data).

B. Risk Measurement

The data gathered by accident investigation boards on legacy systems can reveal valuable insight for the design of the next generation of systems, but only if properly analyzed to put it in useable form. The first step of making this accident investigation data usable is to quantify the level of risk that the identified issues present. The safety community analyzes hazards based on the probability of occurrence and the likely severity should an accident occur. For DoD mishaps, the severity is determined by the class of accident as defined in DoD Instruction 6055.7. These are compatible with MIL-STD-882D suggested mishap severity categories. The values are quantified as shown in Table 1. The composite score of any one issue is determined by average severity level of the mishaps in which the respective issue was identified.

Table 1. Severity Classification

MIL-STD-882D			DODI 6055.07			Quantified
Category	Level	Summarized Criteria	Mishap Class	Summarized Criteria	Floor Class	Value
Catastrophic	I	> $1M, death or perm. total injury	A	> $1M, death or perm. total injury, loss of a/c	A	**3**
Critical	II	> $200K, perm. partial injury	B	> $200K, perm. partial injury	B	**2**
Marginal	III	> $10K, non-perm. partial injury	C	> $20K, non-perm. partial injury	C	**1**
Negligible	IV	< $10K, minor medical	--		<	**0**

The probability analysis uses the mishap probability levels listed in AFI 91-301 which states expected occurrence on a per flight hour basis. This is compatible with the suggested probability values delineated in MIL-STD-882D. The method is applicable to any system safety program if the correct probability values are used. For instance, the values for risk severity could be replaced by those used in the FAA System Safety Handbook and the method would apply to civilian mishaps. The values are quantified as shown in Table 2.

Table 2. Frequency Classification

MIL-STD-882D			System Safety Program Plan (IAW AFI 91-301)				Quantified
Category	Level	Probability of occurrence	Category	Probability of occurrence	Floor per flt hr	~ 5 yr rate	Value
Frequent	A	$> 10^{-1}$ (per FY)	Frequent	$> 10^{-4}$ (per flt hr)	10^{-4}	950	**4**
Probable	B	$> 10^{-2}$ (per FY)	Probable	$> 10^{-5}$ (per flt hr)	10^{-5}	95	**3**
Occasional	C	$> 10^{-3}$ (per FY)	Occasional	$> 10^{-6}$ (per flt hr)	10^{-6}	9.5	**2**
Remote	D	$> 10^{-6}$ (per FY)	Remote	$> 10^{-7}$ (per flt hr)	10^{-7}	0.95	**1**
Improbable	E	$< 10^{-6}$ (per FY)	Improbable	$< 10^{-7}$ (per flt hr)	<		**0**

The analysis of HFACS codes by severity can be very enlightening. For example, Wiegmann and Shappell (2003) found that judgment errors are more often associated with major accidents while procedural and execution errors more likely with minor accidents. This correlation implies that the severity of a mishap is not simply a function of bad luck and shows the potential value of such analysis. Our risk rating matrix, shown in Table 3, is consistent with the MIL-STD 882D format. Using programmatic data it is a simple transform to express it in the format used by the Risk Management Guide for DoD Acquisition (2006) or the FAA System Safety Handbook (2000).

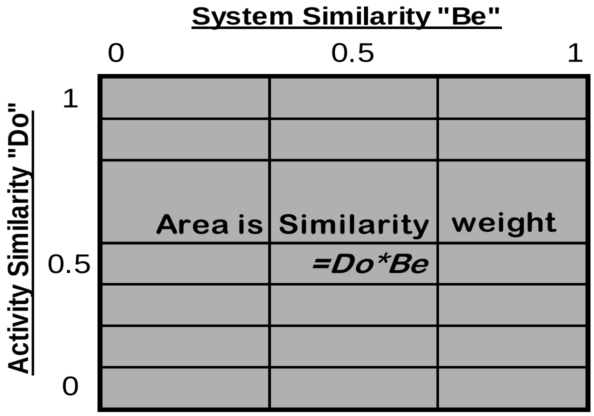
Table 3. Risk Matrix

	Severity of Mishap			
Frequency of Mishap	*Negligible*	*Marginal*	*Critical*	*Catastrophic*
Frequent	0	4	8	12
Probable	0	3	6	9
Occasional	0	2	4	6
Remote	0	1	2	3
Improbable	0	0	0	0

C. Similarity Measurement

In our method, each mishap is also given a similarity weighting based on commonality with the proposed system. This is a novel component of mishap analysis, but increases the relevance of the resultant data for developers. Our similarity factor matrix, shown in Table 4, captures the expected similarity of operator-vehicle interactions as the product of two dimensions: activity similarity and system similarity. This is sometimes referred to as the “Do-Be” weighting. Unlike the risk measurement, the similarity measurement must be tailored to a specific system under study.

Table 4. Similarity Matrix



The activity similarity rating defines the relationship between the activities that have surrounded mishaps and the proposed activities of the system under study. These are quantified at three levels as shown in Table 5. The first is the broad class. For aircraft, this means all mishaps that were aviation related are at least this similar. The second and third levels are defined in Table 4 as the general activities and their respective detailed categories. This list covers all activities identified in AFSC mishap investigations.

Table 5. Activity Similarity Classification

Operational	Contribution	Similarity Weighting	Notes
Broad Class	0.682	0.682	1 std deviation, Normal
Activity, general	0.272	0.954	2 std deviation, Normal
Activity, detailed	0.042	0.996	3 std deviation, Normal

The system similarity rating compares the system characteristics of those involved in mishaps and the system under study. These are quantified at three levels as shown in Table 5. The first is the broad vehicle class. For aircraft, this means all heavier-than-air powered aircraft. The second and third levels are more specific. For military mishaps, the second level of system similarity is the model/mission design series (MDS). An MDS is the symbolic designation of aircraft type and model. This follows AFI 16-401, AR 70-50, and NAVAIRINST 13100.16 for the Departments of Air Force, Army, and Navy, respectively. A mishap aircraft reaches the third level of system similarity if it is the same, or a direct replacement for, the system under study. For future systems, this is would be the designated replacement which is a match in crew configuration, general performance, and design. The similarity factor of a mishap is the product of the similarity for both the involved activity and system. Each HFACS code is then given a similarity factor which is the average similarity weighting of all instances.

D. Significance

HFACS codes are each assigned a value that is their average risk measurement weighted by their similarity factor. We have named this parameter the *significance*. Recent studies indicate the need for this step in mishap analysis. The 2008 AFSC annual mishap report compared manned and unmanned aircraft. This juxtaposition revealed that none of the top four causes of mishaps are the same for manned aircraft mishaps and UAV mishaps (AFSC, 2009). This implies that the occurrence of specific human errors is a function of the system characteristics.

E. Mapping to the domains of human systems integration

The final step is to express these findings in the categorization of the acquisition community. Program managers and systems engineers study the human components of their systems as part of a human systems integration (HSI) plan (DoD, 2008). HSI is normally expressed through its nine domains recognized by the DoD. Mapping HFACS codes into these domains is not just a bridge between two lists, but two separate paradigms. Mishap investigators use HFACS to study an event that occurred with an existing system; they want to capture the causes of the accident. Systems engineers increasingly use HSI domains as part of development (or upgrades) to create a system that does not yet exist; they want to know the important contributions to developmental success. We performed informal interviews with veteran systems engineers and program managers to get their views on where each of the 147 DoD-HFACS codes fit in the HSI domains. For the complete mapping, refer to a Tech Report in DTIC (Hardman & Colombi, 2009).

Table 6. Activity List

Activity, general	**Activity, detailed**
Ground Operations	Maintenance
	Crew actions
Takeoff	Runway
	Carrier
	Austere
	Helicopter/Vertical
Landing	Runway
	Carrier
	Austere
	Helicopter/Vertical
Aerial Refueling	Provide fuel
	Receive fuel
Ground Attack	Direct engage
	Bomb release
Aerial Combat	Close range
	Extended range
Cruise	ATC/Navigation
	Night/Weather
	High altitude
	Low level
	Emergency/Unplanned event
	Formation
	Surveillance ops
	Airdrop
Acquisition/Development	(Policy/processes)*

Table 7. System Similarity Classification

Physical	Contribution	Similarity Weighting	Notes
Vehicle Class*	0.682	0.682	1 std deviation, Normal
MDS Class	0.272	0.954	2 std deviation, Normal
Same weapon system	0.042	0.996	3 std deviation, Normal

Tool and Application

We developed a spreadsheet-based tool to implement the method. The tool is called Requirements Elicitation through Legacy Accident Analysis (RELAAy) and was built using Microsoft® Visual Basic® for Applications (VBA). See Figure 5. It is available for download for approved recipients.

Figure 5. RELAAy tool layout

To demonstrate this new tool and method, we apply it to design decisions for a new multi-role unmanned aerial system (UAS) called the MQ-X. While the method can readily apply to a broad range of analyses, the unique challenges of UAS design highlight the advantages of the proposed methodology over current practice. The MQ-X is planned to have the capability to transition commercial airspace, give and receive aerial refueling, and perform surveillance, reconnaissance, close air support, and strategic strike.

The data used for this study was all US Air Force aviation-related mishaps in which HFACS was identified as a contributory or causal factor between fiscal year (FY) 2004 and FY 2008. The data range begins in FY 2004 because that is the earliest mishaps that were coded with the current HFACS. The data ends with FY 2008 because that is the latest in which all mishap investigations have been completed. This data was analyzed using the RELAAy tool. As new data becomes available, the RELAAy tool can be updated using its built in update function. Within this date range, AFSC cited 902 HFACS issues accounting for 207 mishaps. Of the 147 DoD HFACS codes, 120 were cited at least once in the five year span.

Risk measurement is independent of the system under study. The RELAAy tool contains this data for all mishaps within the data range. It was derived as described in the method. The first finding of interest is that mishaps where HFACS codes were involved were found to be over 6 times more severe, measured in cost of damage, than the average for all mishaps during the same time period.

Unlike risk measurement, similarity measurement must be tailored specifically for the system under study. For the MQ-X, the activity similarity weights were assigned as shown in Table 7. The proposed MQ-X activity information was obtained from the system description documents. The assigned values are consistent with the weighting scheme presented in the method section, which is the default for the RELAAy tool.

System similarity weights were assigned to the aircraft identified in the mishap data. These weights were based on the similarity of system characteristics to the MQ-X as listed in the system description documents. The assigned values are consistent with the weighting scheme presented in the method section, which is coded as the default for the RELAAy tool. For example, mishaps involving the MQ-9 Predator (which the MQ-X will eventually replace) was given a system similarity weight of 0.996 while those involving a C-5 transport aircraft were given a 0.682.

The significance of each HFACS code to the MQ-X program is derived from the risk measurement of the code and the similarity measurements of the involved aircraft as described in the method. Figures 6 and 7 show the RELAAy tool analysis output. Figure 6 depicts HFACS risk, while Figure 7 is the distribution of significance of the respective HFACS codes to the MQ-X development program. As it can be seen by using the legend, RELAAy also maps the distribution of the HFACSs codes among the HSI domains.

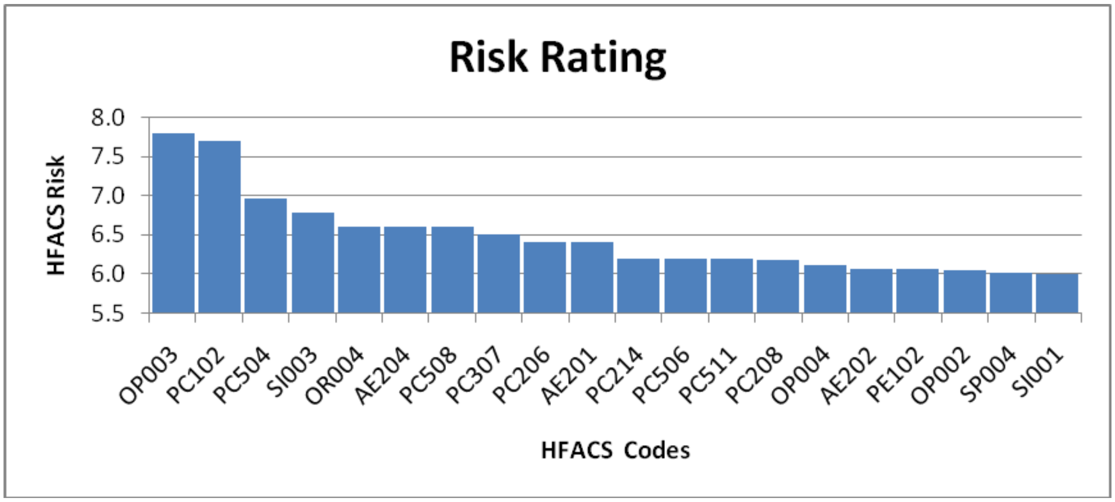


Figure 6. Top 10 HFACS Risks (not yet weighted by Similarity)

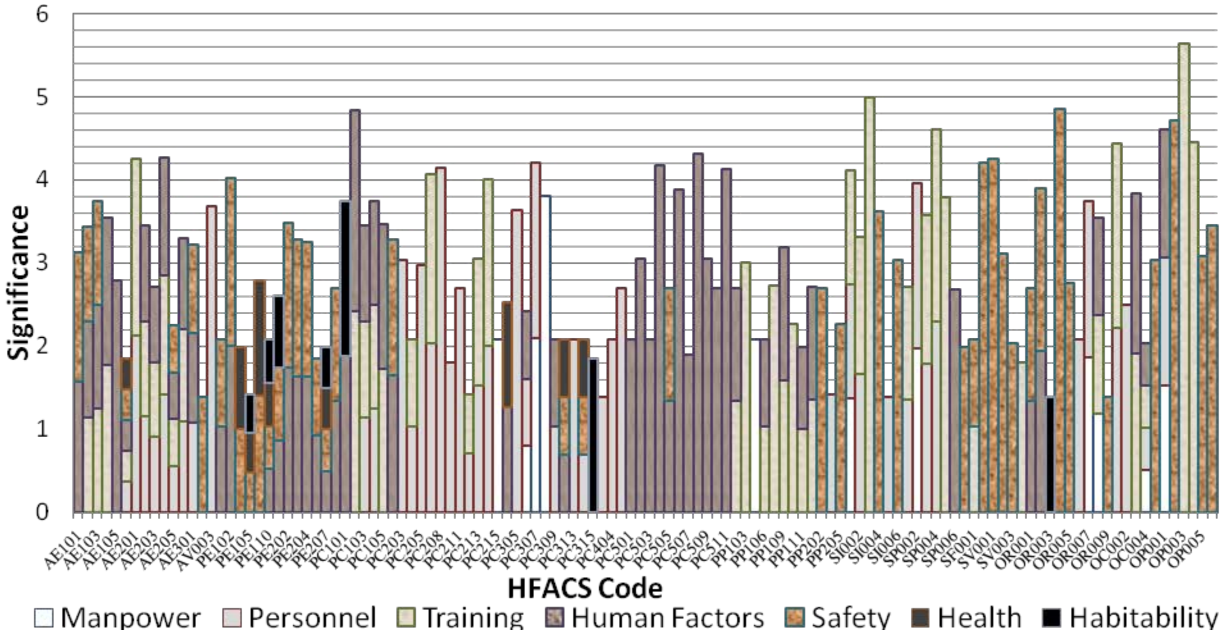


Figure 7. Program Overview, MQ-X Study

Table 8 lists the issues identified as most significant for the program; i.e. the top ten peaks from Figure 7. The general trend is consistent with more generic UAS mishap studies by Tyaryanas (2006), but Table 8 reveals the considerable effect that the similarity factor makes in the prioritization of issues. We found that half of the top ten causal factors would not have been identified by a generic (i.e., not tailored for similarity) risk measurement. Work is currently being accomplished to validate this prioritization and to propose improved weighting schemes.

Table 8 Top HSI Requirements, System under study: MQ-X

HFACS	Description	Related Domain(s)
OP003	Procedural Guidance/Publications	Training
SI003	Local Training Issues/Programs	Training
OR004	Acquisition Polies/Design Processes	Safety
PC102	Channelized Attention	Training, Human Factors
OP002	Program and Policy Risk Assessment	Safety
OP001	Ops Tempo/Workload	Human Factors, Manpower, Personnel
SP004	Limited Total Experience	Training, Personnel
OP004	Organizational Training Issues/Programs	Training
OC001	Unit/Organizational Values/Culture	Training, Personnel
PC508	Spatial Disorientation 1 Unrecognized	Human Factors

Engineers with subject matter expertise in various domains were queried regarding the results. The consensus was that these findings expressed what their experience told them to be true. For example, one engineer with a background in training system development said of the prioritized requirements, “That figures! The pubs, guidance, and local training programs are always the last to get funded and the last to be planned for” (Wirthlin, 2009). Another said, “This method could finally give answers when the PM (program manager) wants to know the necessary representation for HSI on integrated product teams” (Mueller, 2009).

Conclusions

Researchers have established the importance of designing systems with the human components in mind. To do this, engineers must elicit and prioritize requirements related to the human components of the system early in system development. This new method is an empirical study of legacy system mishaps involving human error as a causal factor. It enables a thorough review of the mishap HFACS data in context to the activity and form of a system under study. However, as one reviewer pointed out, our approach depends upon the right HFACS being recorded during the safety investigations in the first place. The typical safety review is typically heavily skewed on personnel and training issues and less on design-related issues. But by applying the similarity weighting and mapping to HSI domains, we can begin to bridge the work of the safety community with the systems engineering processes. With updates to the human error taxonomies and mishap data, this method can remain relevant for the complex human-machine interaction of the aerospace industry.

Biography

John Colombi, Ph.D. is an Assistant Professor of Systems Engineering at the Air Force Institute of Technology. He teaches graduate courses in systems and enterprise architecture and leads sponsored research in architectural analysis, quality of service and human systems integration. Before joining the faculty, Dr. Colombi led systems engineering for the US E-3 AWACS aircraft and managed C4ISR systems integration efforts. Prior, he served at the National Security Agency developing biometrics and information security and ran communications networking research at Air Force Research Laboratory.

Major Nicholas Hardman, USAF is a doctoral student at the Air Force Institute of Technology, Wright-Patterson AFB, Ohio. His dissertation research is focused on how to better integrate humans into system design. Nick attended the US Air Force Test Pilot School and has performed flight evaluations for the first GPS-based weapons. He has a BSEE, MSEE and a Master in aviation systems management. Upon graduation, he will assume the position of Chief Systems Engineer for the C-5 Modernization Program.

References

AFSC. 2007. *USAF aviation safety year in review FY2006.* Kirkland AFB, NM: Air Force Safety Center.

———. 2009. *USAF aviation safety year in review FY2008.* Kirkland AFB, NM: Air Force Safety Center.

Dekker, S. 2004. *Ten Questions about Human Error*. Burlington, VT: CRC.

———. 2006. *The Field Guide to Understanding Human Error*. Burlington, VT: Ashgate.

DoD. 2008. *DoD Instruction 5000.02: Operation of the Defense Acquisition System*. Washington, DC: DoD.

Fiorino, F. 2006. Fighting Human Error. *Aviation Week & Space Technology* 165. 47-49.

Hardman, N. S. and J. M. Colombi. 2009. *A mapping from the DoD human error taxonomy codes to the domains of human systems integration.* Wright-Patterson AFB, OH: Air Force Institute of Technology. Tech. Rep. AFIT/EN/TR-09-04.

Haskins, C., ed. 2007. Systems engineering handbook: A guide for system life cycle processes and activities. Version 3.1. Rev. by K. Forsberg and M. Krueger. Seattle: INCOSE.

Johnson, C. 1999. Why Human Error Modeling Has Failed to Help Systems Development. *Interacting with Computers* 11. 517-524.

Li, W. 2006. Pilot Error and Its Relationship with Higher Organizational Levels: HFACS Analysis of 523 Accidents. *Aviation Space and Environmental Medicine* 77. 1056-1061.

Mueller, M. (2008). Human Systems Integration - What's It All About? *INSIGHT* 11(2).

———. 2009. Personal Interview.

Narkevicius, J., Winters, J. & Hardman, N. 2008. Talking the Talk: Cross-Discipline Terminology Challenges, *INSIGHT* 11(2).

Reason, J. 1990. *Human Error.* New York: Cambridge University Press.

———. 1997. *Managing the Risks of Organizational Accidents.* Aldershot: Ashgate Press.

Rolfsen, B. 2009. Pilot Error Cited in C-17 Crash. *Air Force Times.* 18 May 2009. 25.

Salvendy, G. *Handbook of Human Factors and Ergonomics.* 3rd ed. New Jersey: John Wiley & Sons, Inc.

Shappell, S. A. and D. A. Wiegmann. 2003. A human error analysis of general aviation controlled flight into terrain accidents occurring between 1990-1998. Oklahoma City, OK: Federal Aviation Administration. Tech Rep. ADA417230.

Shappell, S. A.,C. Detwiler, K. Holcomb, C. Hackworth and D. A. Wiegmann. 2007. Human Error and Commercial Aviation Accidents: An Analysis Using the Human Factors Analysis and Classification System, *Human Factors* 49. 227-242.

Stanton, N. A., D. Harris, P. M. Salmon, J. M. Demagalski, A. Marshall, M. S. Young, S. W. A. Dekker and T. Waldmann. 2006. Predicting Design Induced Pilot Error using HET (Human Error Template) - A New Formal Human Error Identification Method for Flight Decks. *Aeronaut. J.* 110. 107-115.

Thompson, W. T., A. P. Tvaryanas and S. H. Constable. 2005. *U.S. military unmanned aerial vehicle mishaps: Assessment of the role of human factors using HFACS.* Brooks City-Base, TX : 311th Performance Enhancement Directorate. US Air Force Tech. Rep. 08-03-2005.

Tvaryanas, A. P. 2006a. *Human factors considerations in migration of unmanned aircraft system (UAS) operator control.* Hanover, Maryland: NASA Center for Aerospace Information. Tech Rep. AD-A444925; HSW-PE-BR-TR-2006-0002; XC-311TH HSW.

———. 2006b. Human Systems Integration in Remotely Piloted Aircraft Operations. *Aviation, Space, and Environmental Medicine* 77. 1278-1282.

White House. 1997. *Final report to the president.* Washington, DC: White House Commission on Aviation Safety and Security. Tech. Rep. per Executive Order 13015.

Wiegmann, D. A. and S. A. Shappell. 2001. Human Error Analysis of Commercial Aviation Accidents: Application of the Human Factors Analysis and Classification System (HFACS). *Aviation Space Amd Environmental Medicine* 72. 1006-1016.

———. 2003a. *A Human Error Approach to Aviation Accident Analysis.* Burlington, VT: Ashgate Publishers.

———. 2003b. *A Human Error Analysis of Commercial Aviation Accidents Using HFACS.* Washington, DC: Office of Aviation Medicine, Federal Aviation Administration. Tech. Rep. DOT/FAA/AM-01/3.

Wirthlin, J. R. 2009. Personal Interview.

.