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A Comparison of Leading and Lagging Indicators of Safety in Naval Aviation.

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Abstract

The purpose of this paper is to examine the results of two different methods of identifying the human factors safety concerns in U.S. Naval Aviation. In both studies, the information was collected using DoD-HFACS (Department of Defense Human Factors Analysis and Classification System). In the first study, aviation mishap data (a lagging indicator) was obtained on 47 F/A-18, and 16 H-60 mishaps. In the second study, the responses of 68 squadrons to a survey regarding the human factors issues that they considered to be of the greatest safety concern were examined (a leading indicator). The results of the first study showed that skill-based errors were the most commonly cited factors for both F/A-18 and H-60 mishaps (70.2% and 81.3% respectively). More specifically, the most commonly used nanocodes were ‘over control/under control’ (27.7% and 56.3% respectively), ‘breakdown in visual scan’ (27.7% and 12.5% respectively), and ‘procedural errors’ (23.4% and 37.6% respectively). The second study identified that the main concern of F/A-18 and H-60 aviators was workload and operational tempo (identified by 85% of squadrons). It can be concluded that the nanocodes that were most commonly used to classify the causes of past mishaps were not identified as major concerns by the squadrons who responded to the survey. The findings from these studies emphasize the importance of examining a number of performance metrics to ensure that effective measures are being taken to improve safety.

Key words: human factors; accidents; safety; leading indicators; lagging indicators; mishap investigation

High Reliability Organizations (HROs), such as naval aviation, place a significant focus on both safety and performance. The reason for this attention is that mishaps have enormous costs in terms of life, loss of multi-million dollar assets, and mission failure. As with other HROs, human error accounts for more than 80% of U.S. Naval aviation mishaps (17). Therefore, improving safety and performance requires the collection of valid and reliable human factors information. In the absence of this type of data, limited resources in terms of money, personnel, and time are wasted.

The purpose of this paper is to examine the results of two different methods of identifying the human factors safety concerns in two U.S. Navy aviation communities. The first study uses aviation mishap data. The use of lagging indicators of safety, such as mishap data, provides historical information about safety performance. The information can be used to influence future safety performance, but it cannot alter the poor performance of the past. The second study details the responses to a survey of naval squadrons regarding the human factors issues that they consider to be of the greatest safety concern. The survey is an example of a ‘leading indicator’ of safety. The use of leading indicators of safety allows issues to be addressed before they result in a mishap.

STUDY ONE: MISHAP ANALYSIS

In 2009, the Commander, Naval Safety Center, issued a directive requiring all future mishap reports to use DoD-HFACS (Department of Defense Human Factors Analysis and Classification System) for the coding of mishap causal factors (1). The DoD-HFACS framework is directly derived from HFACS (see 17 for a detailed discussion of HFACS). DoD-HFACS has

an overall structure very similar to that of HFACS. The main difference between the frameworks is the inclusion of an additional level of fine-grain classification in DoD-HFACS. Each DoD-HFACS category has between one and 16 associated nanocodes (there are a total of 147 nanocodes in DoD-HFACS). Due to limitations of space, DoD-HFACS is not delineated in this paper. The reader is directed to (4) for a detailed outline of the nanocodes.

Although HFACS has been shown to have reasonable levels of reliability for aviation mishap classification when the responses of pairs of well-trained expert have been compared (15,17), issues regarding the reliability and validity of DoD-HFACS have been raised in the literature. O'Connor (9) examined the validity and utilitarian criteria of DoD-HFACS by examining how 123 naval aviators used the system to identify the human factors causes of two written naval aviation mishap scenarios following two hours of DoD-HFACS training. It was concluded that more parsimony, increased mutual exclusivity, and training were required to utilize DOD-HFACS effectively. Similarly, Hughes et al (6) carried out an assessment of the inter-rater reliability of four safety investigators who used DoD-HFACS to classify the causes of 54 U.S. Air Force. It was found that acceptable levels of reliability were only reached in 52% of the nanocodes.

Despite the issues with the reliability and validity of DoD-HFACS, this is how the data was provided to the authors in both of the studies reported in this paper. The possible lack of validity and reliability DoD-HFACS are certainly a limitation of these studies, and the findings should be considered with this in mind. However, to a greater or lesser extent, these are issues with any mishap classification system. There is a large literature on biases associated with mishap reporting (e.g. 12, 18), and the difficulty in developing classification systems that adequately capture human factors information (16).

The purpose of the first study described in this paper is to examine the mishap causal factors that have been categorized using DoD-HFACS for two naval aviation communities- the F/A-18 Hornet, and H-60 Seahawk helicopter. The F/A-18 is a carrier-capable multirole jet, designed to attack both ground and aerial targets. The H-60 is a helicopter used for a wide range of missions (e.g. anti-submarine warfare, search and rescue, cargo lift). The reason for the focus on these two specific platforms is that the Naval Safety Center has recently recoded all of the investigation reports of class A mishaps (a mishap in which the cost of damage to property or aircraft exceeds \$1,000,000, or an aircraft is destroyed or missing, or any fatality or permanent total disability results from the direct involvement of naval aircraft, 1) for these types of aircraft using DoD-HFACS from 2000 until present.

Method

Data was obtained from the Naval Safety Center on all Navy F/A-18 and H-60 class A mishaps from FY2000 until FY2008. The data consisted of 47 F/A-18 mishaps, and 16 H-60 mishaps. The mean mishap rate for the F/A-18 was 2.58 mishaps per 100,000 flight hours, and 1.37 per 100,000 flight hours for the H-60 over the nine years of mishaps examined. The mishap causal factors have been coded into DoD-HFACS by experienced analysts from the aeromedical branch of the Naval Safety Center. The inter-rater reliability of the analysts was not examined. However, the analysts had received training in using DoD-HFACS, and routinely use the system to classify the human factors causes of aviation mishaps. A total of 227 (62 unique) nanocodes were used to categorize the F/A-18 mishaps, and 134 (55 unique) were used to categorize the H-60 mishaps. The study was exempt from Institutional Review Board (IRB) approval as no individual identifiable information was obtained.

Results

Table I summarizes the data by category level. The percentage of mishaps in which each category is cited is presented. (Since each mishap may cite more than one category, the percentages do not sum to 100%.)

Table I. Percentage of mishaps that have one or more causal factors from each DoD-HFACS category.

	% of mishaps	
	F/A-18 n=47	H-60 n=16
Skill-based errors	70.2	81.3
Judgment & decision errors	34.0	50.0
Misperception errors	2.1	6.3
Violations	17.0	31.3
Physical environment	10.6	31.3
Technological environment	10.6	12.5
Cognitive factors	40.4	25.0
Psycho-behavioral factors	23.4	43.8
Adverse physiological state	23.4	25.0
Physical/mental limitations	0.0	6.3
Perceptual factors	23.4	25.0
Coordination/communication/planning	31.9	68.8
Self-imposed stress	4.3	0
Inadequate supervision	27.7	43.8
Planned inappropriate operations	4.3	12.5
Failure to correct a known problem	6.4	6.3
Supervisory violations	2.1	0
Resource /acquisition management	6.4	6.3
Organizational climate	0.0	12.5
Organizational process	27.7	31.3

Table II summarizes the percentage of mishaps in which specific nanocodes were utilized. In the interest of space, only those nanocodes that were used to classify the mishap causal factors in three or more mishaps in at least one of the communities are shown (this

represents 82.8% of the F/A-18 nanocodes, and 70.4% of the H-60 nanocodes). Once again, since each mishap may cite multiple nanocodes, the percentages do not sum to 100%.

Table II. Percentage of mishaps utilizing specific nanocodes (only those nanocodes that were used on at least three occasions are shown).

Levels	Categories	Nanocodes	% of mishaps	
			F/A-18	H-60
Act	Skill based error	Procedural error	23.4	37.6
		Over control/under control	27.7	56.3
		Breakdown in visual scan	27.7	12.5
		Inadequate anti-g straining maneuver	8.5	0
	Judgment & decision error	Risk assessment during operations	4.2	43.8
		Task misprioritization	2.1	18.8
		Decision making during operations	21.3	18.8
		Necessary action- delayed	6.4	0
	Violations	Violations- routine/widespread	8.5	12.5
		Violation- lack of discipline	12.8	18.8
Preconditions	Environmental factors	Vision restricted by meteorological conditions	10.6	12.5
	Cognitive factor	Channelized attention	14.9	6.3
		Cognitive task oversaturation	14.9	0
		Negative transfer	10.6	0
		Confusion	6.4	6.3
	Adverse physiological state	Fatigue- physiological/mental	14.9	0
		Effects of G-forces	6.4	0
	Psycho-behavioral factors	Complacency	10.6	18.8
		Misplaced motivation	10.6	18.8
	Perceptual factors	Spatial disorientation (unrecognized)	0	18.8
		Misinterpreted/misread instruments	12.8	0
	Coordination/communication/planning	Crew/team leadership	12.8	18.8
		Cross monitoring performance	6.4	37.5
		Challenge and reply	6.4	18.8
		Mission planning	8.5	25
Mission briefing		2.1	31.3	
Supervision	Inadequate supervision	Leadership/supervision/oversight inadequate	10.6	37.5
Organizational influences	Organizational process	Local training issues/programs	14.9	25
		Supervision- policy	10.6	25
		Procedural guidance/publications	14.9	31.3

Discussion

It can be seen that skill-based errors was the most commonly cited DoD-HFACS category for both naval aviation communities (see Table I). A closer examination of the types of skill-based errors that occurred in the F/A-18 and H-60 communities revealed that ‘over control/under control’ (an inability to control the aircraft), ‘breakdown in visual scan’, and ‘procedural errors’ were the most commonly used nanocodes (see Table II).

Breakdown in visual scan is defined as “a factor when the individual fails to effectively execute learned / practiced internal or external visual scan patterns leading to unsafe situation”. (p. 2; 4). This nanocode relates to both the internal scan of the cockpit instruments and displays, as well as the information that is available from looking out of the window. An effective visual scan is crucial for what Endsley (5) defines as level one situation awareness. In the absence of an effective scan, aviators will not have an accurate mental model of the current, or future state, of the aircraft. The breakdown in visual scan also relates to the precondition level nanocodes of ‘channelized attention’ and ‘cognitive task oversaturation’, which each accounted for 15% of mishaps in the F/A-18 mishaps. Therefore, it is important that aviators are trained to maintain an effective scan, especially when in high stress and high workload situations.

“Procedural error is a factor when a procedure is accomplished in the wrong sequence, or using the wrong technique, or when the wrong control or switch is used” (p. 2; 4). To address procedural error it is necessary to examine the reason for the error. Although naval aviators extensively rehearse the use of emergency procedures, it is suggested that even more emphasis could be placed on practicing the use of procedures during stressful, high workload, scenarios in the simulator. However, for the H-60 mishaps, poor procedures and guidance were identified at

being casual in 31% of mishaps. Therefore, it is suggested that H-60 squadrons should closely scrutinize the procedures used by aviators to examine their suitability from a user perspective.

Judgment and decision making failures featured prominently in the classification of the F/A-18 and H-60 mishaps (see Table I). Looking at the nanocode level, 2.1% of mishaps were attributed to ‘task misprioritization’ in the F/A-18 community compared to 18.8% in the H-60 community (see Table II). Task misprioritization is a factor when the individual does not organize, based on accepted prioritization techniques, the tasks needed to manage the immediate situation (4). Although speculative, the difference in task misprioritization may be due to the differences in the crew composition between the F/A-18 and H-60. The H-60 has a crew of two pilots and a crew chief (an enlisted crewman responsible for anything that happens in the back of the helicopter and also serves as the pilots’ eyes in the rear and side of the aircraft). The F/A-18 either has a single pilot, or a pilot and a Naval Flight Officer (NFO; responsible for airborne weapons and sensor systems, but does not actually fly the aircraft). It may be that having two pilots with overlapping roles may lead to an increased incidence in crew coordination breaking down in the H-60 as compared to the F/A-18. Further evidence in support of this argument comes from the high proportion of H-60 mishaps that included a breakdown in cross monitoring performance (see later for a discussion).

‘Risk assessment during operations’ was cited in 43.8% of H-60 mishaps compared to 4.2% for F/A-18 mishaps (see Table II). It is suggested that this difference may be due to differences in the operating environments and missions of the two aircraft. As the H-60 is a helicopter, as opposed to a fighter jet, it is more affected by issues such as weather or other environmental conditions than the F/A-18. Also, some of the missions of the H-60 (e.g. search

and rescue) will require the crew to carry out risk assessments due to changes in the operation that could not have been considered in the planning of the mission.

A total of 18.8% of the H-60 mishaps were attributed to ‘decision making during operations’ compared to 21.3% of the F/A-18 mishaps (see Table II). Support for the need for U.S. Naval Aviation to focus on decision making under stress was also found in a study of the Crew Resource Management (CRM) attitudes of U.S. Naval Aviators (see 10 for more details). Thus, there would appear to be a need to focus upon aviator decision making. It is suggested that naturalistic decision making theory should be used to form the theoretical background of any method designed to improve decision making (see 7 for a discussion of this theory).

The rate of violations, particularly by H-60 aviators was higher than that for F/A-18 aviators. Shappell et al. (15) suggest that although decision making can be improved through scenario-based training, this approach is unsuccessful for reducing violations. Violations require leadership to enforce current standards and develop a squadron culture in which violations are unacceptable. Therefore, it is unsurprising to see that 38% of H-60 mishaps were associated with inadequate leadership (see Tables I and II).

Failures in ‘coordinating/communication/planning’ were particularly high in H-60 mishaps (69%), with the focus predominantly upon the failure to ‘cross-monitor performance’ (38%), and poor ‘mission briefing’ (31%; see Table II). The failure to conduct an adequate briefing is something that should be addressed as a violation. However, ‘cross-monitoring performance’ should be addressed during both simulator and CRM training.

The mishap analysis would appear to offer some clear areas where F/A-18 and H-60 squadrons should devote time and resources to improve safety. It is suggested that rather than addressing all of these issues on an individual basis, the use of scenario-based training, in

addition to more traditional classroom-based CRM training may offer an effective method for providing instruction to aircrew on the issues identified above (violations being the notable exception). There is a large amount of research literature on designing effective simulator scenarios, training simulator instructors, and methods for providing feedback to trainees on performance. A combination of lectures, practice of desirable behaviors, and feedback on performance is an established mechanism for delivering effective training (10). However, the analysis of mishap data only provides one picture of where investments in safety should be made. The following study provides a different method of using DoD-HFACS to identify areas of safety concern.

STUDY TWO: HUMAN FACTORS SURVEY

Following a string of mishaps in the first half of FY2008, Commander, Naval Air Forces (CNAF) conducted a ‘strategic human factors review’. One part of the review was concerned with obtaining feedback on the top five human factors issues in naval aviation squadrons. This information was obtained using the DoD-HFACS nanocodes. The goal of this study is to describe the feedback from this survey, and determine whether it provides a unique insight into factors that may not be captured in a mishap investigation.

Method

Data was obtained from CNAF on the responses from 32 F/A-18 and 36 H-60 squadrons. The study was exempt from IRB scrutiny as no individually identifiable information was obtained. The squadrons provided CNAF with their top five human factors concerns. The exact words of the message asking for the information were: “each unit will identify the top five

human factors issues in the squadron using human factors analysis and classification system (HFACS) terminology. This can be accomplished by analyzing current issues or predicting the cause of the next aviation mishap”. No specific guidance was provided on how the information was to be solicited from squadron members.

Unfortunately, the paper authors were not able to obtain the data from each individual squadron. Rather, the data obtained was summarized by type wing. A type wing consists of a number of squadrons of a single type of aircraft. The Navy’s F/A-18 squadrons are divided into two type wings, and the H-60 squadrons into four type wings. The data available for analysis was the top five human factors concerns for each type wing (identified by DoD-HFACS nanocode) with the number of squadrons that had selected each DoD-HFACS nanocode as one of their top five human factors concerns (e.g. op tempo/workload was the most commonly selected nanocode in Type Wing A, and selected by 12 squadrons).

Analysis. Given the squadron level information was not available, it was necessary to use a methodology that would provide a measure of the ‘importance’ of the nanodes. To integrate the data from the type wings, the following method of weighting the ranking of the nanocodes by the number of squadrons was used: the most commonly identified type wing nanocode was multiplied by 5 and then multiplied by the number of squadrons that selected this nanocode as part of their top five safety concerns; the second most commonly identified type wing nanocode was multiplied by 4 and then multiplied by the number of squadrons that selected this nanocode; and so on for the five nanocodes listed.

To illustrate, let’s suppose that that for Type Wing A operational tempo/workload was the most commonly identified nanocode, occurring in 12 of the squadrons’ top five nanocodes. In type Wing B operational tempo/workload was the second most commonly identified

nanocode, occurring in 9 of the squadrons' top five nanocodes. To provide a cumulative index of importance of operational tempo/workload, the following calculation was carried out: $(5 \times 12) + (4 \times 9) = 96$. This methodology controls for where the nanocode was ranked in each of the type wing's top five nanocodes, as well as weighting the value by the number of squadrons that selected the nanocode.

This process was carried out for each type wing, and summed independently for the two F/A-18 type wings, and the four H-60 type wings. Finally, the two sets of data were normalized on a scale of 0 (the nanocode did not appear in the top-five for any type wing) to 100 (ranked in position one by every squadron in every type wing, and included in the top five of every squadron) so that a comparison could be made between the two communities.

Results

Table III shows the weighted and normalized scores for every nanocode that was selected as being a top five human factors cause for each type wing. For comparison purposes, the percentage of mishaps in which the nanocode was identified as a causal factor in the first study is also shown.

Table III. Normalized survey data with associated nanocodes from study one.

Level	Nanocodes	F/A-18		H-60	
		Survey	Mishap (%)	Survey	Mishap (%)
Act	Procedural error	10.0	27.7	0	68.8
	Task misprioritization	4.4	2.1	0.8	18.8
Preconditions	Cognitive task oversaturation	4.4	14.9	4.0	0
	Distraction	0	0	0.8	6.3
	Overconfidence	0	0	1.3	12.5
	Complacency	10.6	10.6	12.4	25
	Motivational exhaustion	6.9	0	5.8	0
	Fatigue physiological/mental	0	0	1.7	12.5
Supervision	Limited recent experience	0	0	0.4	0
	Limited total experience	0	0	1.7	0
	Proficiency	7.5	2.1	39.6	0
Organizational influence	Ops tempo/workload	78.1	4.3	90.3	0
	Change/Deactivation	0	0	0.6	0
	Organizational structure	0	0	2.5	0
	Operator support	0	0	2.5	0

Discussion

It is unfortunate the specific human factors concerns of each individual squadron could not be obtained. However, this is a common problem with using pre-existing data sets of which the researcher has no control. Another limitation is that only two members (the flight surgeon and aviation safety officer) of a squadron are likely to have been trained in the use of DoD-HFACS, and there was no prescribed methodology by which each squadron selected the nanocodes.

Nevertheless, the results of the survey unequivocally identified that the main overarching concern of naval aviators in the F/A-18 and H-60 communities is workload and operational tempo (see Table III). A total of 85% of the 68 squadrons identified this nanocode as one of their

top five human factors concerns. Given the deployment schedules of U.S Naval Aviation squadrons, this finding is not surprising. Operational tempo is an issue that can only be addressed by senior leadership.

Operational tempo (or work pressure as it is generally called in non-military environments) has consistently shown a positive relationship with accident rates. For example, Cooper and Phillips (2) found significant differences in perceptions of work-pace between accident involved and non-accident involved workers. Diaz and Cabrera (3) found that employees' perceptions of the organization's philosophy of either production or safety, was the second most important factor (after organizational policies towards safety) in predicting safety performance. Sanders, Patterson and Peay (14) found that increased levels of production pressure were associated with increased lost time injury rates. Similar to work pressure, there is also evidence to suggest that individuals who are experiencing chronic stress are more likely to be involved in an accident. The results reported by Pfeifer, Stefanski and Grether (13) indicated that supervisors in low-accident rate mines were significantly less inclined to push hard for production or to cut corners on safety

In the H-60 squadrons, proficiency also seems to be a concern of many squadrons. This may be related to the skill-based and judgment decision errors commonly identified in the mishap data analysis. However, it can be seen that the most common causal factors identified from the mishap data are different from those nanocodes identified in the squadron survey (see Table III). It is possible to offer a number of reasons for the dissimilarity between these two data sources.

A mishap investigation generally starts at the crash site and works backwards in time to establish the sequence of events that caused the accident. "The first thing the Aviation Mishap

Board must do is discuss everything that could possibly have led to the mishap, then reject those things too remote to consider... The mishap investigation is a search for causes; it looks for undetected hazards and tries to identify those factors that caused the mishap.”(p.6-18; 1).

However, as investigators consider identifying causal factors further back in the organization at the supervisory and organizational influence levels, it may become increasingly difficult to authoritatively cite these nanocodes in a mishap investigation. Further, Li and Harris (8) make the point that mishap investigators may have difficulty identifying abstract concepts such as ‘operational tempo/workload’ and linking this back to the cause of the mishap.

In contrast, respondents to the CNAF strategic human factor review were not constrained by normal mishap investigation procedures. These respondents were free to choose the nanocodes they believed most likely to cause future accidents without the burden of providing evidence to support their assertions. Given the freedom from identifying specific causes, they were able to take a broader perspective on the human factors concerns of their squadron. This may explain the use of nanocodes at the supervisory and organizational influence levels that allow for the identification of broad human factors issues such as ‘proficiency’ or ‘operational tempo’, rather than specific nanocodes such as ‘failure of scan’ or ‘over/under control’. It could be argued that because this information is based upon opinion, rather than objective facts, it is biased. Nevertheless, expert opinion is commonly used in the behavioral sciences to obtain insight into phenomena that cannot be accessed in other ways. Further, the high levels of agreement between the squadrons would suggest that operational tempo is a pervasive concern for both H-60 and F/A-18 aviators.

GENERAL DISCUSSION

It is recognized that there are concerns with the reliability and validity of DoD-HFACS, and the consistency with which it has been applied (particularly in the second study). This is certainly a limitation, and this is something that should be considered in the interpretation of the findings. Nevertheless, despite these limitations (which to a greater or lesser extent are common to all mishap coding systems) it is felt that the stark differences in the findings from the two studies is worthy of reporting.

The results of the two studies reported in this paper emphasize the danger of organizations focusing too specifically upon major mishaps. Obviously, major mishaps should be carefully investigated, and safety improvements made based upon the findings. However, the conclusions drawn from investigations of major mishaps only represents a partial picture of the safety issues that should be addressed. Particularly in domains in which mishaps are rare, it is important to examine the analysis of minor mishaps as well as other safety performance metrics. Researchers working in HROs should develop useful leading indicators of safety performance that are used in addition to the traditional lagging indicators of safety, such as mishap data. It is suggested that it is the responsibility of researchers to develop a method for integrating these different sources of information so that senior leadership can readily use the knowledge to make informed, data driven, decision to improve safety performance.

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