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Applying Lessons from Safety-II Proof of Concept in Line Operational Safety Audit to Aviation Maintenance

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Introduction

Aviation maintenance is an environment with high system complexity and much human involvement. These factors can make aviation maintenance activities prone to errors that are not immediately noticed. Some mistakes do not become apparent until an accident or incident has occurred (Langer & Braithwaite, 2016). With the aviation industry typically succeeding in avoiding catastrophes while operating in a high-risk environment, the standard measure of using lagging indicators to assess safety performance is difficult (Gazica et al., 2018). The lagging indicator style of feedback could mean that aviation maintenance personnel may be conducting unsafe maintenance practices before the error is uncovered. Some research has shown that a blame culture also exists in aviation maintenance, making the reporting of mistakes problematic at best (Langer & Braithwaite, 2016). The goal of any safety program is to keep the number of unsafe events acceptably low for the environment, the public, and the workers (Hollnagel, 2014).

A measure of acceptably low is subjective; regulation will specify the threshold of safe operation while the public opinion may indicate that any aviation accident with a loss of life is unacceptable (Langer & Braithwaite, 2016). For the commercial aviation industry, the acceptable level of safety is established and monitored by a regulatory agency, such as the Federal Aviation Administration (FAA) in the United States, and is defined for each individually based on the target level of safety for each different service provider (SKYbrary, 2021a). American Airlines (AA), with the support of senior leadership, has started to explore new means of improving safety in the cockpit with an invitation to the airline industry, and other industries, to collaborate and share methods and ideas to improve safety (SKYbrary, 2021b).

The question to be researched is if the application of new safety theories beyond the cockpit and in an aviation maintenance environment could mitigate unsafe maintenance

practices before said practices result in the realization of an aviation accident with loss of life. Stakeholders who would benefit from this research are the aviation maintenance certificate holders who perform maintenance. Considering the aviation maintenance environment's description from Langer and Braithwaite (2016), expansion beyond a centralized control of procedural safety would be beneficial. Direct observation on the flight deck of an aircraft is a normalized part of pilot assessment while direct observation of maintenance actions on aircraft is unusual, even for training and assessment. Such observations have the potential to change the behavior of the maintainer because of the sense of intrusion by the observer into normal maintenance operations. Flight crews also typically have immediate feedback on undesired aircraft states while maintainers do not have the same benefit (Langer & Braithwaite, 2016). Secondly, other stakeholders who would benefit would be the aircraft's aircrew; improvements in aviation maintenance safety could lead to more airframe availability and reliability. Third, the ultimate stakeholder would be the aviation customer participating in commercial flight operations with less risk from maintenance errors. This research has significance for aviation safety with the potential to reduce the risk of maintenance errors and the identification of organizational safety constraints that may be evaluated again to validate the necessity of those specific constraints in the aviation maintenance environment.

Background

AA began exploring Safety-II to improve risk management in the cockpit and beyond in 2018 (SKYbrary, 2021b). Dr. Erik Hollnagel published many works on Safety-II and accident prevention starting in the early 2000s, and AA's safety leadership became interested in the concepts he had developed. Dr. Hollnagel focuses on intelligent man-machine systems, cognitive systems engineering, human reliability analysis, and resilience engineering and is, at the time of

writing, the Senior Professor of Patient Safety at the University of Jonkoping, Sweden (Hollnagel, 2021). While AA currently operates under what Dr. Hollnagel would describe as Safety-I, AA wanted to further explore the concepts of Safety-II through their Line Operational Safety Audit (LOSA) program. The goal for AA's Learning Improvement Team (LIT) is to develop proof of concept, refine the program to expand beyond their LOSA, and introduce the program to the aviation industry. In addition to working directly with Dr. Hollnagel, AA's LIT has partnered with The Ohio State University to help maintain alignment with the Safety-II principles and continue rigorous data collection methods (AA Department of Flight Safety [AA DFS], 2020).

Initially, AA's LIT worked with hand-selected AA Check Airmen to collect data in a narrative format from pre-identified crews noted as high performers during regular flights. This narrative format was difficult for AA's LIT to work with, and the data collection method was changed from narratives to an objective data-oriented approach. This data collection tool, hosted on Microsoft Excel, went through rapid prototyping, and resulted in no less than six versions (AA DFS, 2020).

In parallel to the data collection efforts, AA's LIT developed a Safety-II model centered on Resilience Engineering (RE). RE has been designing resilience into hardware and software systems and those methods have been applied to complex socio-technical systems where human performance is necessary for overall system resilience. In that complex system, AA's LIT postulates that RE has a central tenet in practice that resilience cannot be built into the system but can be developed by the organization and the individual workers that lead to resilient performance. In AA's LIT's model, learn, plan, adapt, and coordinate are the four factors that lead to resilience as developed through the study of the LOSA program. The new model

contrasts with the currently understood Safety-I program that AA pilots now use. Currently, AA pilots operate under the “ABCs for Threat and Error Management (TEM); actively monitor and assess potential for error, balance available barriers to avoid & trap errors, communicate threats & intentions timely & effectively, follow SOPs.” (AA DFS, 2020, p. 8).

Statement of the Problem

With Safety-II decentralizing safety decision-making, decentralization could be an appropriate method to use in the regulated environment of aviation maintenance. With AA conducting a proof of concept of Safety-II in the LOSA, the potential exists to expand the proof of concept to the aircraft maintenance environment (AA DFS, 2020). The expansion could give first-level supervisors a dynamic means of addressing the performance of some maintenance tasks that arise during aircraft maintenance that may violate a centralized organizational safety policy. However, the applied approach is still compliant with 29 CFR § 1910 *et seq* Occupational Safety and Health Standards (1974) regulations. The violation of an overly restrictive organizational safety standard during some aircraft maintenance actions can allow aircraft maintenance to occur, reducing the risk of a maintenance error and improving the aircraft’s overall safety.

Methodology

The method used in this study is a case study based on the white paper from the AA DFS (2020) and their work on implementing Safety-II into their LOSA. The research was conducted by searching for peer-reviewed articles relating to Safety-II, LOSA, and safety surveys. The white paper released information from the AA DFS (2020). The search terms for the peer-reviewed articles from the last five years are “Safety-II,” “Line Operations Safety Assessment,” “Aviation Maintenance Safety Surveys,” “Safety Surveys,” and “Aviation Maintenance Safety.”

Hollnagel's (2014) book on Safety-I and Safety-II was included. The sources were subjectively analyzed based on the article abstract and selected for inclusion based on Aviation Maintenance Safety, LOSA, and Safety-II theories. The methodology, results, and discussion of the sources selected were reviewed to ascertain relevance of the study in relation to this work and to find results that either supported or contradicted findings of the other sources used. A case study was appropriate for this study as a real experiment is not feasible. AA is conducting a quasi-experiment of Safety-II application in a limited capacity in their LOSA program (AA DFS, 2020). Lagging indicators of risk realization is a factor that would prevent an experiment in the aviation environment. Organizational risk assessments of experimentation may result in unacceptable risk for organizations as the consequences of a realized risk have a potential for serious injury or death. While other industries are starting to apply Safety-II theories, many of those industries are operating in environments that could be more forgiving than the environment the aviation industry is working in. A true experiment in the true environment carries an unacceptable level of risk for all the stakeholders.

Literature Review

Safety Culture

Safety, as defined by Provan et al. (2020), is the "...ability for a system to perform its intended purpose, whilst preventing harm to persons" (Introduction, para. 2). For some operations, safety is the combined actions and decisions of anyone interacting with the system. Organizational leaders create a safety culture by prioritizing safety to influence the employees to hold safety as a priority (Provan et al., 2020). Safety culture is described by Key et al. (2020) as the employee's perception of how much an organization values safety and the level of risk

acceptance in accomplishing tasks. The work environment also plays a role in shaping safety culture (Key et al., 2020).

A familiar term in the aviation industry is “safety climate.” Safety culture and safety climate share similar abstract ideas (Chiu et al., 2019). Safety climate is intended to reduce injuries and accidents by affecting the employee perceptions of policies and practices in the organization. Safety climate is designed to work through a centralized safety practice that encourages compliance with the policies and practices through managerial behaviors and procedures. Research has shown that safety outcomes have a link with safety climate.

Gazica et al. (2018) conducted a study on a limited population of aviation flight students. They found a significant relationship between individual safety motivation and personal feelings of participating in their occupational calling. Those individuals who felt they were called to the occupation of flying had higher safety motivation than those who did not feel the same. The study did note the limit of generalizability to other aviation populations and presents opportunities for further research. Other research has found that safety climate has been a predictor for safety motivation and the intention to adhere to safety policies, which has been a predictor of organizational safety performance (Gazica et al., 2018).

Current Aviation Maintenance Safety

Aviation maintenance safety culture is measured and assessed with surveys. Large employers have the resources available to fund a workforce survey that includes analysis and interpretation from professionals. Smaller organizations may not have the resources available for a similar assessment. Large and small organizations face a similar problem with employee surveys: participation is typically low, and the responses may not be sincere. The lack of

sincerity comes from anonymity concerns, specifically, if management can identify individuals based on information such as shift or job role (Key et al., 2020).

In a military aviation maintenance environment, safety climate and command culture surveys are used as the primary means of assessing the individual perception of safety in the squadron, like other maintenance organizations. The surveys are conducted and analyzed by an external contracted company, with results only presented to the squadron commander. However, the extensive collection of demographic data, including rank, military occupation code, division, and maintenance shift, led many to believe they could be identified by the command and singled out for their responses, like the blame culture noted by Langer and Braithwaite (2016). The consensus in the division was the survey was another task to be completed, a task that would not result in any changes to safety or safety culture in the squadron because of insincere responses from most respondents. Anonymity was assured through providing the answers seemingly desired by the command.

Safety-I

Khoshkhoo et al. (2018) described the three categories of errors: spontaneous errors, errors linked to threats, and additional errors resulting from a chain of events. Those errors should be controlled from a Safety-I standpoint through predictive and proactive measures (Khoshkhoo et al., 2018). Safety-I is the method typically used in Aviation; for American Airlines, the Threat and Error Management (TEM) process uses procedures, checklists, automation, external resources, and crew experience to monitor proactively, balance, and communicate threats (AA DFS, 2020). From Safety-I perspective, the employees are liabilities to safety where the safe environment is typified as an absence of accidents and incidents.

With the idea of preventing an incident as a mainstay, incidences may result in further updates and new procedures that further restrict the employees' work. The new restrictions are meant to limit the freedom of choice for employees responding to work situations with the idea of reducing any human error in the work conducted (Jones et al., 2018). The addition of restrictions is consistent with what Hollnagel (2014) describes as a Safety-I myth where the causes of threats can be prevented, thus improving safety. The resulting idea is that a zero-defect or zero accident environment is the ideal environment and can be attained through mitigating threats (Hollnagel, 2014).

Though there is much support for current centralized safety practices in aviation, these practices have some weaknesses. Safety culture can vary inside an organization, from the front-line personnel in the hangar to the management staff. Chiu et al. (2019) point out that the proximity to risk between the different groups in the organization influences risk decision making and is consistent with the culture-structures-processes model regarding the change in the strength of safety culture at various organizational levels. With the close links between the organizational structure, safety culture, and the resulting decisions, there are recommendations to use safety training to influence an organization's safety culture.

Chiu et al. (2019) conducted a study to develop a predictive model and found a few surprising results. For individuals, no significant relationship was found between safety training and the individual valuation of safety. This result does not suggest stopping safety training but continuing research into safety training to determine the benefit to the organization (Chiu et al., 2019).

The gap in the ability of Safety-I to account for and control risk is summed up by Hollnagel (2014):

This problem was addressed 30 years ago when the British psychologist Lisanne Bainbridge, in a discussion of automation, pointed out that ‘the designer who tries to eliminate the operator still leaves the operator to do the tasks which the designer cannot think how to automate.’ This argument is not only valid for automation design but applies to work specification and workplace design in general (p. 126).

Safety-II

Safety-II focuses on decentralizing control when it comes to complex, dynamic, and variable systems or environments. An idea behind Safety-II is the proactive management of risk and viewing deviations from the procedure as attempts by the workers to manage a complex system (Jones et al., 2018). Hollnagel’s (2014) idea is to switch from asking what can go wrong to questioning how and why things go right in unexpected and expected conditions. The switch in idea can lead to understanding why adjustments and variability of performance lead to success (Hollnagel, 2014). Safety-I procedures do not account for system complexity, and the workers attempt to negotiate the grey areas between procedure and efficiency to meet mission goals. These negotiations result in procedural violations that occur in many different fields, most of which were never intended to cause harm (Jones et al., 2018).

This work leads into RE, where systems are developed and operated to adapt to the variable conditions of the environment where they operate (AA DFS, 2020). Wahl et al. (2020) describe RE as “...a key concept for ensuring safety in complex socio-technical systems” (Introduction, para. 2). A similarity between RE and Safety-II is the importance of performance variability and how organizations and people adapt to changes. The difference in view on variability contrasts with the tenets of Safety-I, where variability is typically associated with a

deviation from a set standard and should be constrained to prevent something from going wrong. RE and Safety-II attempt to control rather than constrain variability to succeed in dynamic environments (Wahl et al., 2020).

A challenge with Safety-II is handling social norms and other external pressures in the work environment. Jones et al. (2018) conducted a study on community pharmacies and procedural violations. Social norms could influence others to violate procedures in an inappropriate situation because that violation is accepted in the work environment for many other similar situations. Other external pressures, such as management throughput goals or business pressure to increase efficiency, result in workers consciously deciding to violate a procedure if the worker, with good intentions, judges the violation to not increase risk in the context of the situation (Jones et al., 2018). Hollnagel (2014) describes such behavior with the Efficiency-Thoroughness Trade-Off (ETTO) principle. Regardless of the restrictive safety procedures, people will have to make trade-offs between thoroughly following the safety procedures and being efficient at their work (Hollnagel, 2014). The Safety-II and Safety-I challenge is managing external pressures in a complex system (Jones et al., 2018).

Applications for Safety-II

The AA introduction of Safety-II into the LOSA program is the only published aviation application of Dr. Hollnagel's principles in the aviation industry at the time of writing. Other industries have applied Dr. Hollnagel's principles into their training programs, such as the maritime industry. Maritime shipping is still a dangerous line of work, with 2,712 casualties and 94 lost ships in 2017. Wahl et al. (2020) conducted a study on the application of Safety-II principles in simulator training for shuttle tanker dynamic positioning systems in offloading oil from an offshore oil field. Each of the participants were qualified, experienced dynamic

positioning system operators. While the tenets of Safety-I were important for the procedural steps of approaching and connecting with the offshore unit, the addition of Safety-II to manage and control variability in sea and wind conditions and managing minor errors in simulation fostered a learning environment where information was shared between peers. Understanding and working with the variability encountered during simulation increased student confidence in the system's operation (Wahl et al., 2020).

Discussion

Safety in aviation maintenance is multi-faceted, with any safety violation having the potential to result in death or serious bodily harm to any of the participants, particularly the airline customers who have no control over the conduct of maintenance or flight. Extrapolating the findings from Gazica et al. (2018) can lead to the conclusion that an aviation maintenance technician who has found their calling may be more thorough with the application of safety regulations than an aviation maintenance technician who is just working a job. They may have a higher valuation of safety than their peers who have not found their calling. However, those who have found their calling in aviation maintenance may still be faced with the ETTO principle described by Hollnagel (2014).

The pressure to complete a maintenance task for the aircraft to be on the flight schedule increases pressure on the aviation maintenance technician; a looming deadline may cause some to become less thorough with safety and more focused on efficiency. Some safety regulations are routinely violated to make a maintenance task more efficient or easier to accomplish. In a hypothetical example, when changing out a bearing in the non-rotating controls of a helicopter, one of the larger sockets from the toolbox would be used to support the collective controls to

make access easier to the bearing. Most of the time, the large socket would be put back into the toolbox after the job.

On one occasion, the socket was not returned to the toolbox and was discovered during the change of shift toolbox inspection. The socket was found, but no changes to procedures occurred because this was an acceptable deviation for efficiency. The accepted deviation may be a good example of the ETTO principle incorporated into acceptable safety violations in a squadron.

There is much value in the application of Safety-I concepts. Aviation maintenance technicians can use published maintenance procedures to keep themselves more on the thoroughness of work side of Hollnagel's (2014) ETTO principle. Thoroughness of work can be accomplished by resisting pleas from management to be more efficient to meet tighter maintenance turnaround times. The inclusion of Safety-II principles can improve the relationship between thoroughness in applying procedure and the need to be efficient.

Using the Safety-II idea of focusing on what went right instead of what went wrong, the previous example of improper tool usage demonstrates a violation of tool control and maintenance procedures. What went right was the change of shift tool inspection resulted in the discovery of the missing socket. What went right was the aircraft maintenance was completed without any injury, the aircraft was available for the flight schedule, and the inspector on the job learned to inspect toolboxes and not explicitly trust senior aviation maintenance technicians. Safety-I processes resolved an issue created through the ETTO principle and the maintenance team's application of Safety-II principles.

Conclusion

Returning to the research question of “if the application of new safety theories could mitigate unsafe maintenance practices,” research in other industries indicates that it may succeed when included with Safety-I processes. However, individual safety valuation is a factor in applying safety policies, and safety training is not significant in affecting personal valuation (Chiu et al., 2019). The normalization of procedural violations also plays a role in the thorough application of safety in the workplace (Jones et al., 2018). More research into applying Safety-II to high-risk aviation organizations is recommended to develop a means to use it for aviation maintenance.

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