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Implementing the REPAIRER Human Factors Safety Reporting System Through MRM (MxHF) to Meet SMS Compliance in Aviation Maintenance

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Abstract. Reiterating the importance of having a human factor related safety reporting system for aviation maintenance to reduce human error and utilizing it to gain SMS compliance, the REPAIRER method of identifying and reporting human factors hazards in aviation maintenance is reintroduced. How and why the REPAIRER method system is of such importance in the implementation of aviation maintenance safety programs can be linked to the success and evolution of maintenance resource management and human factors programs which have been effective in reducing human error in aviation maintenance. These programs are rooted in effective communication methods, as well as the identification of human factor elements. To illustrate this point, the successes of maintenance resource management are discussed. Additionally, the incredible strides that the Federal Aviation Administration (FAA) has taken to propel a human factors-centered safety program in aviation maintenance are brought to light with the FAA's latest transition of MRM (Maintenance Resource Management) to MxHF (Maintenance Human Factors). This newly appointed program, which replaced a decades old FAA MRM program, highlights the significant changes in MRM, notably the emphasis on human factors. Given the significant shift from MRM to MxHF, the authors explore the implementation of the REPAIRER aviation maintenance reporting system under the new guidelines and demonstrate how it could fulfill many of the desired outcomes of both programs, while still gaining SMS compliance.

Keywords: REPAIRER Reporting System · SMS · MRM · MxHF

1 Introduction

In 2018, the authors presented a paper entitled, "The REPAIRER Reporting System for Integrating Human Factors into SMS for Aviation Maintenance" at the AHFE Conference linking together risk management with human factors in the form of a safety reporting system for use in aviation maintenance to satisfy the FAA's new encouraging policy of SMS for commercial aviation in the US. The theoretical aviation maintenance safety reporting system came in the form of an 8-step acronym called the 'REPAIRER' Reporting System [1]. ICAO's (International Civil Aviation Organization) SMS

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Table [2] was used as the foundation to support the theory, as seen in Fig. 1, which contains four safety pillars (Policy, Promotion, Assurance, Risk Management). Although this model is a good fit for commercial aviation operations in the US, it was deemed deficient for commercial aviation maintenance operations in the US due to the fact that the SMS model lacked the integration of human factors. This deficiency was further supported by relevant research in aviation maintenance, which was compiled over the last 30 years. The results of that research indicated that maintenance error is consistently due to human error, with high percentages of error related to maintenance manuals and procedures. With human error in aviation maintenance established as a problem, the next step was to review the methods of human factors training currently in use, industry-wide. Two models were found; Transport Canada's 12 dirty dozen and the FAA's PEAR model. This ultimately led to the creation of the REPAIRER reporting system for aviation maintenance, as a new way that human factors could be merged into the SMS table via the Risk Management pillar. The new reporting system was also supported through the Safety Assurance pillar. In theory, the REPAIRER Reporting System appears to be a viable solution for aviation maintenance safety moving into the future. But how can something that looks so good on paper truly work in reality?

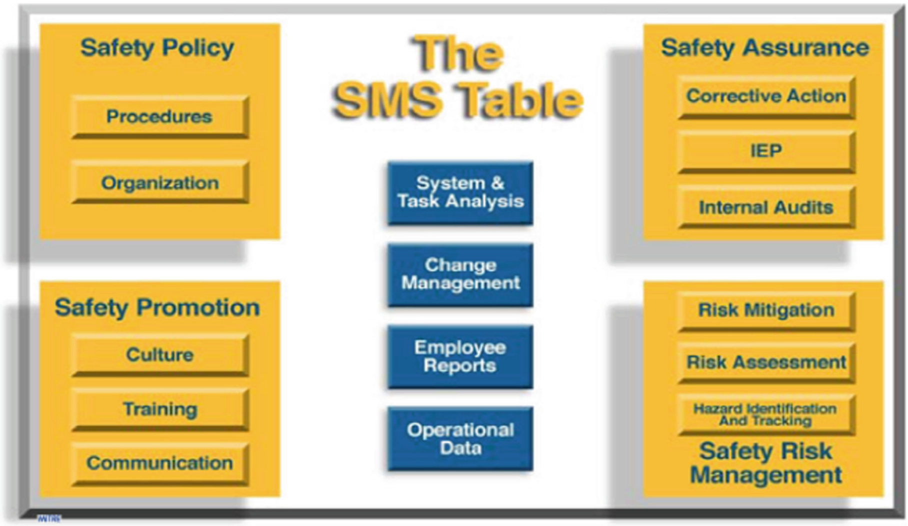

Fig. 1. The SMS Table [2]

2 Implementing REPAIRER into Aviation Maintenance

Where the REPAIRER Reporting System becomes a reality is by executing two more of the SMS pillars: Policy and Promotion. The Policy pillar is formally putting the REPAIRER into writing, by explaining how it will be implemented in the organization. The Promotion pillar is taking the Policy on REPAIRER, and training personnel on how to effectively use the system, ensuring adequate organizational support during the process. Although executing these two pillars seems straightforward, this is not always the case. Aviation maintenance organizations require high levels of output to remain profitable; at the end of the day, it is a business and as such is economically driven. Decisions are financially-based. Aircraft that cannot fly represents waste. It is crucial therefore, that aircraft maintenance be performed efficiently and effectively in order for these organizations to remain in business. There is also a balance that must be achieved between safety (through adherence to FAA regulations and inspections) and efficiency. Any imbalance of safety or efficiency can be dangerous. That is why the REPAIRER Reporting System, which emphasizes risk management and human factors in SMS, is so important. It balances both safety and efficiency in aviation maintenance.

The other challenge related to the REPAIRER implementation is culturally-based. In many cases, maintenance decisions are economically-based, leaving little room for debate or consideration. As long as FAA regulations are not compromised, the most efficient method is normally selected. After operating this way for years, introducing new processes may be met with resistance. However, there are examples of aviation maintenance organizations that have taken the next step and gained in safety and efficiency, due to what is notably referred to as Maintenance Resource Management (MRM).

3 MRM as the Historical Linkage to Making REPAIRER a Reality

MRM [3] origins can be traced to Cockpit Resource Management (CRM), which started at NASA and was then adopted by United Airlines in the early 1980s after United crashed a DC-10 in 1979 into a Portland, Oregon neighborhood after the aircraft ran out of fuel. The root cause of the accident was found to be miscommunication between the Captain and the crew members. The Captain mismanaged his time, while the crew failed to be assertive. Following the accident, United implemented what was to be a paradigm shift in the cockpit. The Captain was no longer the end all for decisions, and teamwork became the cornerstone of aircraft operations. United had so much success with their cockpit safety tool, that the rest of the industry soon followed. The FAA would eventually make CRM training mandatory on an annual basis for all US airlines. This training was, and still is, heavily centered around human factors and the tenants of teamwork, communications, assertiveness, task delegation, management and leadership. The industry-wide adoption of CRM in the US changed the cockpit culture from a dictatorship to one of teamwork and crew coordination that has reduced human error and greatly increased safety.

The idea of MRM came about roughly a decade after the United Portland accident in 1988, when an Aloha Airlines 737 lost a large section of the fuselage roof during departure from the Kona, Hawaii airport. Unfortunately, a flight attendant was lost in the decompression, but the pilot and crew did a magnificent job handling the emergency and were able to land safely at Kahului, Maui. The accident investigation revealed that failed inspections did not pick up 240 cracks in the skin of that aircraft's ceiling. Aloha's management group was technically knowledgeable and had the expertise, but organizational human factors had reduced the effectiveness of the Aloha maintenance program. From this accident the US airline industry and the FAA began to address teamwork deficiencies in maintenance and decided to design a product that would address human factors similar to those found in the cockpit and CRM. The idea was that CRM addressed immediate, critical effects of human error in the cockpit, so why couldn't a similar model be designed to address the often-latent critical effects of human error in maintenance? The MRM format focussed more on building better communications, teamwork, effectiveness, and safety in aviation maintenance, while at the same time it also is attentive to a wider audience of maintainers that includes AMNTs, inspectors, engineers, staff support personnel and managers. Eventually the FAA encouraged all commercial aviation organizations in the US to adopt MRM.

4 The Success of MRM in the US Industry

Continental Airlines was the first to implement an MRM program [4]. Taken from their successful CRM system, the Crew Coordination Concept (CCC) was formed. Designed specifically for maintenance personnel, the program leveraged communications and teamwork in order to improve safety and efficiency. Within one year, Continental Airlines realized a 66% reduction rate in lost workday injuries and mishaps after training 66% of its personnel. A three-year study of that program concluded with significant positive effects on safety, assertiveness, teamwork, stress management and dependability. CCC reduced maintenance error rates and improved human reliability, which further deemed the program a success. It was so successful that many other large airlines started MRM-related programs of their own. US Air [5] started a form of MRM in 1993 that involved not only US Air maintainers and management personnel, but also the labor union and the FAA FISDO. Teams were formed to rewrite the procedures manuals. This program was so successful that in 1996, US Air Management initiated a joint Labor-Management safety process and MRM was the vehicle to do it. Taylor [6] concluded in 1997 that employee involvement, open communications, and commitment to purpose, with improved technical content in a maintenance system, increased maintenance safety, efficiency and performance at both Continental and US Air. Taylor found that both Airlines reaped impressive returns on investment from using MRM programs. A major goal of MRM is to reduce human error through teamwork and effective communications. To determine the extent of this reduction, Patankor and Taylor [7] measured lost time injuries and aircraft ground damage variables at an airline maintenance facility from 1995 to 1999. The data resulted in a decline in both variables during the time period. The data also showed the importance MRM refresher training. However, in 2008, Patankor and Taylor [8] reviewed current MRM programs in the US industry and found that although initially personnel liked the new MRM programs, which in turn increased performance, this unfortunately changed over time. AMNTs and engineers became frustrated with management, which ultimately discouraged MRM initiatives. Trust between the AMNTs, engineers and management declined. The trust ingredient, along with good communications, are essential to promoting an MRM safety culture. The organization as a whole must have a strong commitment to MRM; these programs provide maintenance employees with nearly limitless tools. Without managerial and organizational commitment however, the best MRM programs cannot be sustained.

5 Success in US Military MRM Programs

After the US commercial industry integrated MRM into aviation maintenance programs with a good deal of success, the US military aviation industry took note and implemented it as well. The US Coast Guard employed MRM in 1998 and from 2002 onward had trained 100% of their maintenance personnel in MRM. As a result, Coast Guard accidents rates resulting from maintenance mishaps increased only slightly between 1998 and 2010. However, during this 12 year period, the cost per maintenance related accidents was kept stable. Considering the rising cost of parts during that time, this was truly a remarkable accomplishment for MRM. Although human error was not measured during the period, the relative stability of maintenance-related accidents for the US Coast Guard combined with the lower cost per accident is a noteworthy trend in support of MRM [9]. Another good example is that of the US Air National Guard. In 2005, an MRM program initiated by the Disruptive Solutions Process was implemented in US Air National Guard aviation units [10] in an effort to decrease maintenance-based aviation mishaps across its 88 flying wings. Over a three year period following the introduction of the MRM program, the US Air National Guard Wing reduced its aviation based maintenance accidents by 75%. In fact, the program was so successful that it was adopted by the US Air Force in 2006.

6 Who Must Use MRM and to What Extent Must They Use It?

Despite the research evidence and successes of MRM programs, the concept has not been formally mandated by the FAA. Although it has been highly encouraged, as quoted in the FAA Aviation Manual: “There are no regulations mandating any type of human factors training program, including MRM-specific knowledge or training.” [11] However, the FAA does list elements of successful MRM programs [12] for maintenance organizations to develop. Understanding the complexities and varying types of aviation organizations, the FAA endorses the following five elements for a successful MRM program: senior management support, training for supervisors and middle managers, continuous communication and feedback, a systems approach and full participation. In addition to those elements, an MRM program usually consists of the following human factors related training themes: assertiveness, communication, team building, conflict resolution, stress management, decision-making and human factors performance elements [13]. Therefore, MRM is more of a recommendation than it is a regulation.

7 The Shift from MRM to MxHF at the FAA

Overall, MRM has been an excellent change agent for reducing human error in aviation maintenance, in both commercial and US military sectors. However, the MRM key elements to success (senior management support, training for supervisors and middle managers, continuous communication/feedback, a systems approach and full participation) can be somewhat difficult to achieve. Unfortunately, the continuous successful usage of the communications and teamwork themes that are taught in MRM do not always work. Failure of any of the key success factors can work against the continuous execution of the human factors practices MRM offers and ultimately hinder the entire MRM program. Management support, for example, can be difficult to foster during times of economic stress. Even if initial MRM training was well-received, if refresher training cannot be provided, the intent and continued success of the program could be lost. Another example would be the relationship between union leaders and managers. Communication and feedback, for example, could easily be affected during union/management contract negotiations. Additionally, using the FAA recommended optimal systems approach for implementing MRM through customized training, which is designed for each maintenance stakeholder, is not an easy task as it requires using an instructional design model like ADDIE (Assess, Design, Develop, Implement and Evaluate). Lastly, having the expectation of full participation in the MRM program is another challenging prospect in any commercial aviation maintenance organization. Disagreements between line technicians, maintenance engineers, and middle managers could result with tension and distrust, which undermines MRM philosophies. From these examples it is easy to see that no matter how good the intentions are to start and maintain an MRM program, neglecting any of the five factors listed could cause the program to fail.

The influence of critical success variables that loom continuously over the US aviation maintenance industry, combined with the fact that maintenance related communication and teamwork training using MRM principles is noteworthy in the prevention of human error in aircraft maintenance, the FAA set out to revise the MRM Advisory Circular of 2005. In 2017, it was upgraded to include a broader scope of aviation maintenance human factors training and reclassified as MxHF (Maintenance Human Factors Training). According to the new FAA circular, MxHF, formally known "A general process of maintaining an effective level of communication and safety in maintenance operations." [14]. The term MRM was used more widely in the 1990s than in the last decade. In comparison, MxHF is more descriptive, all-encompassing and widely used in the US aviation maintenance industry today.

8 MxHF

By being more descriptive and all-encompassing, MxHF takes on the following definition given by the FAA for human factors, "a multidisciplinary field that generates and compiles information on human capabilities and limitations, and applies it to design, development and evaluation of equipment, systems, facilities, procedures, jobs, environments, staffing, organizations and personnel management for safe, efficient and effective human performance." [15] Since 2005, Human Factors training has taken on important aspects related to communications and teamwork in aircraft maintenance environments through MRM. MxHF covers the human factors previously identified in MRM, but expands on it. Common topics that can be found in MxHF training programs include the following: human factors introduction, safety statistics, safety culture and organizational factors, human performance and limitations, the physical work environment, human error, physiological factors, communication at work, and hazards in the workplace [16]. With online training materials already available through the FAA or CASA (Civil Aviation Safety Authority of Australia) websites, MxHF training programs are not as difficult to implement. With more of an emphasis placed on comprehensive human factors training, the opportunity for an aviation maintenance safety reporting system is clear. The REPAIRER reporting system tool leverages human factors elements to effectively identify and prevent the occurrence and likelihood of human error in aviation maintenance. Such a system would bridge the gap between human factors and human error using MxHF and other safety protocols recently mandated by the FAA such as SMS.

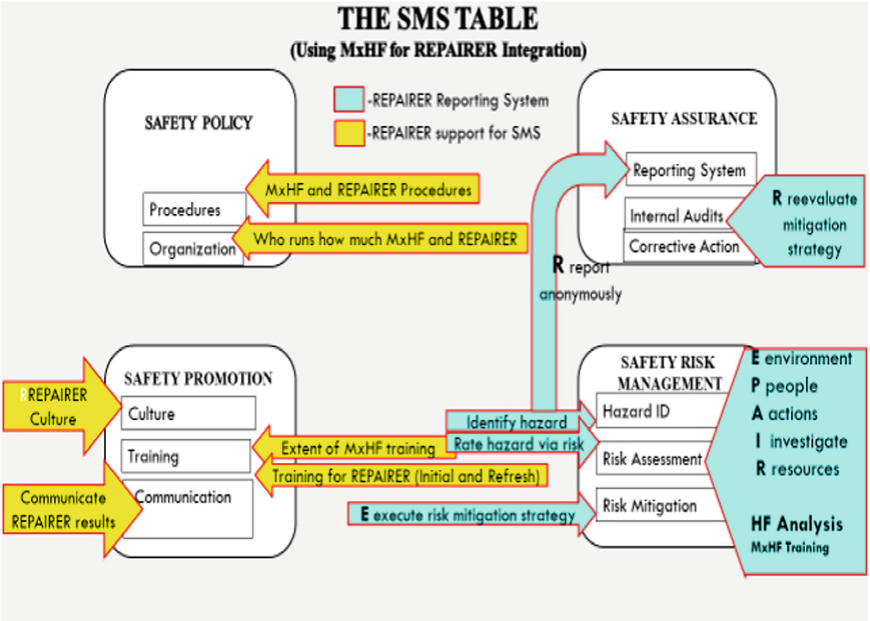

Fig. 2. The SMS Table [2] with the REPAIRER Reporting System fully integrated by using MxHF. All four support pillars of the SMS Table integrate either the REPAIRER Reporting System (blue) or REPAIRER system support (yellow). By Mark Miller 2019.

9 Integrating REPAIRER into the SMS Table Using MxHF

As depicted in Fig. 2, the implementation of the REPAIRER Reporting system into an aviation maintenance organization is now feasible. Through the recent creation of MxHF and the inclusion of the FAA's recent mandate that all US commercial airline maintenance organizations implement an SMS program, the new REPAIRER reporting system was formed. By replacing MRM, MxHF now encourages a broader range of human factors training. This element, combined with the SMS mandate, brings risk management and safety to the aviation maintenance environment more formally than in previous decades. Prior to these programs, most aviation maintenance organizations in the U.S. did not make optimal use of maintenance human factors (except in the form of team/communications through MRM) and even fewer were using a Risk Management process. As seen in Fig. 2, all four pillars of the SMS Table (Safety Policy, Safety Promotion, Safety Assurance and Safety Risk Management) can now be supported by both human factors and operational risk management through the REPAIRER Reporting System. To have such a system in aircraft maintenance that clearly addresses human factors hazards through an operational risk management process is of utmost importance for these organizations. The biggest threat in maintenance is human error. To stop or minimize this threat, the REPAIRER Reporting System must first be addressed via the Safety Policy pillar.

10 SMS Safety Policy and REPAIRER Integration

When implementing the REPAIRER Reporting System into an aviation maintenance organization, it is imperative to first formally write down the scope of the program, as depicted in Fig. 2 under the Safety policy pillar. Procedurally, the details of the REPAIRER Reporting System need to be laid out as a road map of how the REPAIRER Reporting System will be run in the organization and for legal liability protection. Because the REPAIRER Reporting System will rely on MxHF training, the specific human factors training which the organization desires must be written as a prerequisite in order to use the REPAIRER Reporting System properly. Once the MxHF training is designated (from what is available on the FAA website), the entire break down of the REPAIRER Reporting System must be explained in relation to that particular maintenance organization in accordance with how each letter of the acronym will be carried out. In doing so, the core area of ‘Procedures’ is carried out in support of the safety policy pillar and SMS requirements. The second core area in SMS Safety Policy that must be addressed is ‘Organization’. It is important to determine who will be responsible for the MxHF training and the overall support for the REPAIRER Reporting System; for this is essential to the overall success of the system. Through both the ‘Procedures’ and the ‘Organization’ aspects of the SMS Safety Policy, the REPAIRER Reporting System essentially has an implementation starting point for the organization.

11 SMS Safety Promotion: Training for MxHF in REPAIRER

Switching now to the Safety Promotion pillar of the SMS table in Fig. 2, both cases of human factors (MxHF) and REPAIRER training, can be tailored and customized for the type and size of the aviation maintenance organization that will utilize the REPAIRER Reporting system. This is relevant as the REPAIRER Reporting System is meant to be cost effective, as opposed to MRM which was costly in terms of training and applicable implementation systems. The REPAIRER reporting system, however, leverages the human factors training materials provided by the FAA. Using the provided human factors analysis, the 'EPAIR' portion of the REPAIRER system is achieved. Other crucial elements that fall under the Safety Promotion pillar include culture and communication. To ensure optimal use, the REPAIRER Reporting System requires initial and annual follow-up training. Continued use allows the tool to be integrated into the existing aviation maintenance culture. Where MRM required a systems approach through the use of a detailed instructional design tool, REPAIRER only requires a computer-based instructional format, or a classroom format if needed. Ideally, the creation of a web computer-based training (CBT) which combined the specific human factors element along with the MxHF training materials would be the most effective form of low-cost training for both initial and refresher REPAIRER training.

12 SMS Safety Risk Assessment: Identifying, Risk Assessment, and Reporting Hazards – 'R' (Reporting Step in REPAIRER)

In the Safety Risk Management pillar of the SMS Table shown in Fig. 2, the first part of the first '**R**' in the REPAIRER Reporting System must be completed. In this initial step, the hazard within the maintenance environment must be identified and assessed using risk management. This would seem like an easy task, but sometimes the hazard can be somewhat difficult as it may be a confluence of human factors errors coming together. Once the hazard has been identified, it then needs be assessed utilizing a risk assessment matrix, noting the severity and exposure as critical variables. These two variables will ensure the hazard receives an accurate rating assessment ranging from low (non-threatening) to high (dangerous) and can be helpful in prioritizing the hazard. This form of rating has been proven successful in the U.S. military for over two decades in the form of Operational Risk Management. It is simple to use and highly effective. High rated hazards need to be addressed first, while low rated hazards can be addressed at a later date or when time permits. Rating the hazard initially also provides the maintenance organization with data on just how dangerous the hazard was prior to the implementation of corrective measures. Once the maintenance hazard has been thoroughly identified and rated, it then needs to be reported. To complete the minimum for reporting a hazard it must be identified, risk rated and then reported into the reporting system. To accomplish this, the '**R**' (Reporting step) shifts in the SMS table to the Safety Assurance pillar in Fig. 2. The idea is to create a Safety Assurance Reporting System which continuously demonstrates that safety is an ongoing process within the maintenance organization. Additionally, by setting up an anonymous reporting system, maintainers will be invited to continuously participate in safety without fear of retribution. If it the reporting system is set up properly, the maintainers will be able to see the hazard they reported and follow that hazard through the process.

13 SMS Risk Assessment: Human Factors Analysis of the Maintenance Hazard – 'EPAIR' (MxHF of REPAIRER)

What sets the REPAIRER Reporting System apart from other popular safety strategies is that it is process driven. It is based on criteria that must be met by each of the four pillars of the SMS table. Secondly, it is centered on being a Reporting System that involves all maintainers in the safety process. Thirdly, it utilizes a scientific risk management rating system and most importantly, it directly links maintenance human factors to human error. Human factors engage several aspects of aviation maintenance: physiological, psychological and ergonomic (human interface engineering). To properly use the elements in maintenance to correct for human error, it is necessary to infuse them into the REPAIRER model via the human factors analysis and risk assessment.

The '**E**' in the EPAIR represents the specific maintenance environment where the actual hazard occurred. This includes the physical layout such as lighting and temperature, but also the internal organizational environment at the time of the hazard. The '**P**' stands for the people involved. Basic things like poor qualifications and training need to be reported along with any physical, physiological, psychological and ergonomic issues that could be relevant to the hazard. The '**A**' in the EPAIR human factors analysis method stands for the actions of the people involved. Because the aviation maintenance research points toward procedural problems in terms of human error causing a high percentage of maintenance accidents, it is important to identify what the people involved with the hazard did or did not do at this juncture. The '**I**' in the EPAIR method stands for the investigation of the proper procedure that was associated with doing the wrong maintenance action in the previous letter '**A**' for action. This step is critical because it is imperative to know exactly how the maintenance action was performed incorrectly, but it is also equally important to know how it should have been done correctly. This step is important because there is a chance that the current procedure is unsafe or inefficient and needs to be amended. The next letter in the EPAIR to complete the human factors analysis in the REPAIRER Reporting System is the 'R'. This is the second '**R**' for the resources that were required in the hazard. If the resources required to complete the maintenance task were inadequate or used improperly in relation to the hazard, they will need to be reported here.

14 SMS Safety Risk Management and Mitigation of the Maintenance Hazard – the 2nd 'E' in REPAIRER (Executing Mitigation Strategy)

With the human factors analysis of the hazard complete, a sound mitigation strategy for the maintenance hazard can now be created. Not only is the human factors analysis a large part of the hazard assessment, but it also plays an important role in finding a solution. The goal of the mitigation strategy is to lower the initial risk rating of the hazard to acceptable levels, making the maintenance organization safe from that particular hazard. At first, the solution is simply a plan on a drawing board. But at some point, the plan will be carried out and the mitigation strategy becomes the 2nd '**E**' in REPAIRER for 'Executing'. It is important to make sure the mitigation strategy is executed and carried out successfully. The challenge with this step is following up on the strategy with some form of reevaluation to prove that it is meeting the original intent of reducing or eliminating the hazard. This is the last step in the REPAIRER Reporting System; '**R**' for 'Reevaluating' the hazard. To accomplish this, it is important to venture back to the Safety Assurance pillar in the SMS table of Fig. 2. Under the Reporting system are two important SMS methods that stand out to ensure that the hazard mitigation strategy was working as expected or not. Internal audits are perhaps the best option through tracking the hazard in the REPAIRER Reporting System and then seeing how successful the mitigation has been. If the audit proves the mitigation strategy successful and the risk has been reduced, then the mitigation strategy has completed its job. However, if the audit finds that it failed to reduce the hazard to safe levels, it is time to make a 'Corrective action' as listed in the Safety Assurance pillar in Fig. 1. and continue to audit.

15 Conclusion: Building a Safety Culture Through REPAIRER

The idea of using a safety reporting system like REPAIRER for aviation maintenance organizations to be the cornerstone of safety is not an unrealistic goal. It has all necessary elements (safety reporting, risk management, and human factors) working together to create an efficient and effective safety process. Timing is also important; in 2019 the FAA encouraged aviation maintenance organizations to use the MxHF aviation maintenance human factors training to replace MRM. To accomplish this, the FAA emphasizes the use of their online human factors training materials. Additionally, the FAA is also encouraging aviation maintenance organizations in the US to adopt the elements of the SMS Table. As demonstrated in the paper, the REPAIRER Reporting System either fulfills the SMS element requirements directly through the REPAIRER or through the necessity of support for the REPAIRER with one exception. The exception occurs under the SMS Safety Promotion pillar in the form of the 'Culture' element within the SMS Table in Fig. 2. To have true, impacting long term success in an aviation maintenance organization, the REPAIRER Reporting System would have to be adopted by the maintainers in that organization as part of their daily operations. To be a REPAIRER culture, everyone in the organization would have to believe in the system and actively work to support it. Maintenance personnel must understand that by using a combination of risk management and human factors that have been integrated with the proven SMS elements, the REPAIRER Reporting System will save lives, resources and improve morale. They will be motivated to use it as it something practical that will seamlessly blend in with their jobs. Organizations that develop successful cultures not only gain in efficiency, but also have highly motivated employees that are engaged and involved, ultimately giving the organization a competitive advantage. A REPAIRER Reporting system for aviation safety is waiting on the shelf and is poised to be implemented into an aviation maintenance organization to form a winning safety culture. The time is now.

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