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Abstract. To resolve the issue of human error in maintenance the REPAIRER reporting system is revisited as it has great potential by combining a human factors analysis with a risk management safety reporting mechanism. It is also timely as a human factors centered safety reporting method like the REPAIRER could now be feasibly implemented through the new mandatory FAA (Federal Aviation Administration) FAR 121 requirement to use SMS (Safety Management System) pillars and through the new FAA MxHF human factors training. With the current FAA support in place and the ever growing need to add human factors to combat human error in aviation maintenance, the REPAIRER model would seem attractive to many aviation maintenance organizations. To illustrate this, the researchers' intention is to take the REPAIRER model to a point of hypothetical use in an aviation maintenance organization to gain an understanding of its potential benefits. To accomplish this, a thorough look at the economic gains were first identified in the form of cost savings through safety and less accidents, but then also in the form of possible efficiency gains. The REPAIRER was then looked at as a tool to achieve employee motivation and gain a just culture. The last area of the REPAIRER added value was the ease of implementing it into various types and sizes of organizations.

Keywords: REPAIRER reporting system · SMS · MxHF · Safety · Efficiency · Motivation · Just culture

1 Introduction

In 2018 and 2019, the authors presented two papers respectively at the AHFE conference. The first entitled, "The REPAIRER Reporting System for Integrating Human Factors into SMS for Aviation Maintenance" [1] was centered around developing a better way to manage safety in aviation maintenance through a human factors analysis integrated into a risk management style reporting system that would comply with FAA (Federal Aviation Administration) SMS (Safety Management System) mandates recently placed on the US (United States) commercial aviation industry operating under FAR121. The acronym of REPAIRER [2] first needs to be revisited as a process that by design has great potential to make a difference if used properly in the aviation maintenance arena. First and foremost it starts off with the first 'R' for reporting and rating the hazard. Then it is joined by a human factors analysis portion to analyze the Hazard

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with ‘EPAIR’. The ‘E’ stands for the environment the maintainers are working in and it is followed by the ‘P’ which stands for the people involved. Where the REPAIRER becomes unique is in ‘AIR’ portion of the human factors analysis. It is here that the ‘A’ requires the actions of the people involved to be studied to determine what they did and did not do. Also important to maintenance is the step represented by the ‘I’ which calls for an investigation of the proper procedures to the maintenance action, as most aviation maintenance errors stem from not following the written procedures properly. To end the human factors analysis portion, the REPAIRER requires the use of a second ‘R’ to look closely into the resources used by the maintainers involved and to see if there were any issues with those resources. Once the human factors analysis is completed a second ‘E’ is tactically placed in the REPAIRER model to execute mitigation strategies. The execute portion is critical as the REPAIRER is not solely focused on analyzing serious problems in maintenance and identifying solutions, but also allows for the implementation of solutions. The final ‘R’ is used to reevaluate those solutions, allowing for future modification if needed. These eight steps not only integrate the steps that should be found in any modern aviation safety system but are also greatly enhanced by edition of a human factors analysis. The second paper, presented in 2019, entitled, “Implementing the REPAIRER Human Factors Safety Reporting System through MRM(MxHF) to meet SMS Compliance in Aviation Maintenance” [3] reiterated the necessity for implementing the REPAIRER reporting system into aviation maintenance organizations, noting the recent shift from the FAA’s traditional Maintenance Resource Management (MRM) program to an online Human Factors training program for maintainers, now referred to as MxHF.

2 The REPAIRER Reporting System and Economic Gains

In an industry where profits are heavily linked to the number of occupied seats on the plane, it comes as no surprise that every dollar spent on safety must have clear financial benefits. While safety is paramount in aviation, there are other critical costs that must also be considered such as daily labor, fuel, and maintenance as they are often used to offset filled seat margins. Maintaining the aircraft is considered one of the three major costs in commercial airline operations, making safety within this area incredibly important. In aircraft maintenance, human error can drastically and quickly challenge established safety standards, harming personnel and/or equipment resulting with revenue losses. Although personnel injury can be very costly, an incident that causes an aircraft to be delayed can contribute to passenger frustration and overnight hotel costs, in some instances. Additionally, accidents related to maintenance malpractice can take these costs to a much higher level, especially if lives are lost or the aircraft is damaged. While monetary losses from human error in aviation maintenance are costly to businesses, what often goes unnoticed are the costs incurred to maintenance technicians that must cover the work for an injured coworker or disappointment of the customer that was unable to arrive on time. In extreme circumstances, an aircraft accident can have lifelong consequences. The lasting grief of family, friends, and crew members can be challenging to overcome. These organizations must work to earn that trust back from its various stakeholders.

Years of research in aviation maintenance clearly points out that the culprit of these unfortunate events is often human error. In many instances that human error is caused by a failure to stay within the guidelines of established maintenance procedures. If human factors is the best way to combat human error in aviation maintenance, then it is highly logical that human factors could lower that cost. However, it is imperative that the method of integrating human factors in maintenance must have clear benefits, from both a safety and efficiency perspective. A human factor reporting system such as the REPAIRER could achieve this economic balance by reinforcing the importance of reporting safety hazards and identifying efforts to mitigate those circumstances.

3 Using a Human Factors Safety Reporting System in Maintenance

A safety reporting system that incorporates human factors allows employees to actively participate in the identification and reporting of hazards. In doing so, they learn the many elements that comprise human error including physical, psychological, and ergonomic factors; all of which directly contribute to aviation accidents. By completing the free online training at the FAA MxHF training site, the aviation maintainer will not only be knowledgeable in reporting hazards, but also help make larger strides to conquer them. For instance, a company working to complete a major maintenance phase during night shift encounters personnel issues. One of the experienced maintainers is home with an injury. The oncoming shift supervisor inspects the job done by the night crew and notices several things wrong. The night supervisor explains that one experienced maintainer is at home with a bad back and the others with less experience had to continue without him. As a result, the night supervisor could not oversee all maintenance work completed during the shift. A scenario like this could be handled in many ways. However, with a REPAIRER reporting system both shift supervisors would recognize the potential for human error, setting the reporting system into motion. A risk management assessment code is then applied to address the poor maintenance completed during the night crew shift.

4 Using a Human Factors Analysis to Identify Root Causes: 'EPAIR'

In the process both supervisors discuss the problem and break it down in terms of human factors. The 'E' environment was broken down, noting the time the work was completed as well as the pressure to finish the inspection phase on time. During the shift, the night crew supervisor noticed that many of the personnel were getting fatigued early in the morning and stress was playing a role. When investigating the 'P' for people, having the experienced maintainer out with a bad back did not help and clearly contributed to the stress. It forced work to be done without proper experience. Further investigation revealed that the experienced maintainer was injured by using improper platform equipment and fell. This is a separate incident and needs to be reported as well. In both cases, the supervisors determine that night crew personnel did not follow

proper procedures; the first from confusion in the maintenance manual and the second from the company platform regulations. The 'I' for investigating the proper procedures revealed that the personnel using the procedures manual that night misinterpreted the directions due to their inexperience and lack of supervision. It was also found that the experienced maintainer used the wrong equipment platform because the correct one was being used elsewhere and the other was broken. The 'R' for resources showed that the proper experienced personnel and the proper equipment were not available.

5 Gaining Safety Data to Study Trends and Manage or Eliminate Risk

From the 'REPAIR' portion of the REPAIRER, significant steps have been taken to improve future safety efforts, while also reducing costs, representing economic gain. By simply reporting the hazard, the information is going into a data base where it can be collected and studied with similar data over time. Rating the hazard through risk assessment means that the hazard can now be scientifically managed, including the probability of future occurrences. While human error in aviation maintenance cannot be completely eliminated, minimizing these threats greatly improves the overall safety of the organization. Reviewing safety trend data allows aviation maintenance managers to take a proactive approach to managing safety. Instead of waiting for repetitive incidents to turn into accidents, these hazardous trends can be faced early on with preventative measures and/or safety techniques, thus reducing the likelihood of a catastrophic event. This represents significant cost savings for the organization. The data from the human factors 'EPAIR' analysis is intended to get to the root cause of the accident in terms of human factors issues. These elements are collected over time and emerge as human factors data categories, allowing hazards to be proactively identified. In the example, fatigue could have been identified as a contributing factor to both incidents. Additionally, other incidents reported from the night shift previously highlighted fatigue as a contributing factor. Therefore, fatigue has become an underlying human factors causation that will be worthwhile to rectify. A solution that addresses the fatigue hazard at night represents cost savings by reducing incidents related to this specific human factor error. These trends can help guide management through intentional decision making. In the example provided, excessive fatigue exacerbated by stress during night shift could be viewed as a trend. Additionally, through the identification of human factor errors, the REPAIRER method can also help to identify and resolve costly injuries resulting from improper adherence to EPA (environmental protection standards) OSHA (occupation safety and health administration) standards. These can add up over time and be just as costly as traditional aircraft incidents. Although the main thrust of the REPAIRER is to reduce costly maintenance mistakes, the value placed on human factors represents cost savings that could benefit all aviation maintenance endeavors. This is due to the synergistic value in the 'REPAIR' portion of the reporting system by combining the popular risk management technique (identify, track and manage hazards) with the details of why they are occurring in terms of human factors.

6 Adding the Process of Continuous Improvement

As powerful as the steps in the 'REPAIR' are for the economic health of the maintenance department, the 'REPAIR' gains its total value by adding the 'ER' steps at the end, bringing together the full REPAIRER system. With the reporting completed, the hazard rated, and the human factors data collected, the REPAIRER has the opportunity to make a greater impact by adding the last 'ER' for process of improvement. The second 'E' in REPAIRER stands for 'execute the mitigation strategy'. The 'R' stands for 'reevaluate' how the mitigation strategy is working. By collecting human factors data, it is now possible to identify a better strategy to correct the hazard. It is in this 'execution mitigation strategy' step that human factors find its way back to its historic beginnings in the form of ergonomics by the studying and improving the man-machine interface. While the REPAIRER reporting system idea is founded on the premise of identifying a safety solution based on accepted levels of risk, there is also a way to turn the safety risk into an efficiency gain. Human factors and the ergonomics of improving the man-machine interface started in the 1800's during the industrial revolution. It utilized scientific management to improve the efficiency of assembly line work. The scientific manager was essentially a human factors expert studying the work of each employee (man-machine interface) on the assembly line via frame by frame pictures until the most efficient way of doing the work was created. The original intent was to make the factory assembly line as efficient as possible, producing maximum economic gains. Procedures to make assembly line work safer did not come until sometime the early 1900's. In the case of REPAIRER and modern aviation maintenance safety, the execution of a safety mitigation strategy comes first. However, if efficiency gains exist then the principles of modern TQM (total quality management) in the form of Lean Six Sigma continuous improvement are welcomed. Under this premise, there are cost savings and economic gains through the execution and reevaluation of the mitigation strategy, which could be greater if the hazard problem has an efficiency solution as well. Given that aviation maintenance is found on standardized procedures, which also creates the opportunity for human error, the use of such a reporting tool is incredibly valuable. In some cases, it is a matter of simply identifying a mitigation strategy to ensure procedures are properly followed. There are cases where new technology could be infused to make the maintenance procedure safer and more efficient, such as altering the way the procedures are completed. In the example provided, given the lack of experience on night shift, the final two 'ER' steps can be completed. Bringing on additional experience from the day crew shift would address the hazard and ensure that proper procedures are followed. Complicated procedures can be scrutinized and altered for efficiency gains. The current working platform must be remedied, and reevaluation goals identified for later adjustments, if needed.

7 REPEARER Becomes a Lean Six Sigma Improvement Method

With the potential for efficiency gains and safety gains, the REPAIRER reporting system now mirrors the 5 phases of Lean Six Sigma continuous improvement process: Define, Measure, Analyze, Improve and Control [4]. The DMAIC acronym starts by 'Defining' the problem which matches the 'Report a hazard step' in REPAIRER. 'Measuring' the problem is accomplished by 'Rating the hazard using risk management' in the REPAIRER. Analyzing the problem is accomplished through the 'Human Factors analysis' in the (EPAIR)' portion of the REPAIRER. 'Improve' the problem is initiated with the 'Executing mitigation strategy' in the REPAIRER. 'Controlling' the problem is completed through 'Revaluating the strategy' at the end of the REPAIRER. DMAIC is used in Lean Six Sigma as an established business practice to improve speed, quality and cost. The phases of DMAIC which define a problem through implementing solutions linked to underlying causes, and then establish best practices to make sure the solutions stay in place are powerful [4]. Using the DMAIC process encourages creative thinking within the scope of the current system, but keeps the basic process, product or service [4]. Although the primary mission of the REPAIRER is safety in aviation maintenance, the same guiding principles used in DMAIC for continuous improvement are also fundamentals in the REPAIRER system.

8 Can Safety and Efficiency Gains Work Together? The Boeing One Plan

One of the best examples of creating a safe, but efficient workplace in an aviation maintenance environment can be found at Boeing's EHS (Environment, Health, Safety) One Plan. It goes beyond a safety plan. It emphasizes continuous performance improvement and sustainability in the areas of zero injuries, environmental leadership and operational excellence. Lean Six Sigma Workshops are continuously conducted throughout Boeing to teach continuous improvement techniques such as accelerated improvement shops, value stream mapping, Kaizen events and structured problem solving [5]. The centralized EHS team moves throughout the company to inspire local solutions as teams identify solutions to safety, environment and operational problems. The solutions are then tested for possible implementation as a new company wide standard. Utilizing safety and health as a pillar of quality supports the use of environmental leadership and operational excellence through the identification of efficiency gains which can be built into industry-wide safety programs [5]. Perhaps the most intriguing point about Boeing's initiative is the resulting impact on workforce motivation. Employees feel they can make a difference to any of Boeing's companies through safety, environmental and operations improvements. The Lean Six Sigma training combined with the encouragement in the formation of work teams to address potential issues is positively transforming the Boeing culture [5]. The REPAIRER system could accomplish similar goals in a maintenance by addressing both safety and efficiency improvements and in the process greatly motivate the workforce.

9 Establish Intrinsic Value, and a Continuous Improvement Just Culture

By the virtue of the REPAIRER having the opportunity to establish both safety and efficiency solutions to cut costs for economic gains, it could also be of intrinsic value. From this the REPAIRER is similar to the enthusiasm recently found at Boeing via the EHS One Plan. The REPAIRER system has the potential to improve different aspects of the workplace, creating an environment where maintenance personnel support and find value in a culture of continuous improvement. The cultural shift experienced at Boeing was rooted in the intrinsic value for its employees. Their behavior was driven by internal organizational rewards, creating a sense of satisfaction.

In Maslow's Hierarchy of Motivational Needs [6], Maslow described this as the top of the motivational pyramid by gaining esteem and ultimately self-actualization as the individual realizes that their full personal potential has been achieved. This is the highest form of motivation and the internal reward therefore comes from a person knowing that they are making a difference. The REPAIRER could also be viewed as an instrument for maintainers to attain esteem, self-fulfillment and be motivated intrinsically. As with Boeing, this motivation could form a culture that leverages the REPAIRER in order to make a difference in aviation maintenance organizations. This type of environment establishes a culture that is not based on fear, blame, or punishment from coercive leadership. Instead it stems from the creation of a just culture; discovering what went wrong and motivating people to come up with innovative ways to fix and learn from their mistakes. With the strength of human factors analysis integrated into the REPAIRER system, the establishment of a just culture is integrated into the culture through an unbiased and no-fault inquiry of identifying what went wrong, but even more importantly properly identifying what the human errors were that caused the problem. Through this lens, the REPAIRER system is poised to improve organizational success in aviation maintenance through economic and efficiency gains, adding intrinsic value to employees' work, and through the formation of a powerful just culture. However, perhaps its greatest value is in its simplicity. The REPAIRER steps could be customized and integrated into any type or size aviation maintenance organization, then tailored as necessary for optimal output. Whether the maintenance organization is a small General Aviation organization, an outsourced venue, a military unit, or a large commercial entity, the REPAIRER and its important elements is an opportunity to make a positive difference in that maintenance organization.

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