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The REPAIRER Reporting System for Integrating Human Factors into SMS in Aviation Maintenance

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Abstract. Acknowledging the FAA's well-known PEAR model, and the influence of the dirty dozen in aviation maintenance, the authors examine a tracking and reporting system that fulfills FAA requirements for safety management systems in aviation maintenance organizations. Implications and suggestions for a robust safety management system which encompasses human factors and ORM, applicable to an aviation maintenance environment are presented, with the inclusion of specific risk hazards. The resulting safety reporting system proposed addresses both consistency and reliability challenges, unique to the aviation maintenance environment. Using the four pillars of safety as a foundation, the REPAIRER strategy procedures serves as the safety policy pillar, through the examination and rating of potential risk hazards, based on the dirty dozen. The resulting reporting system leverages aviation maintenance-specific factors to identify and correct for human errors, improving the reliability of maintenance procedures, enhancing safety practices, and ultimately creating a greater state of operational readiness.

Keywords: Aviation maintenance · Human factors
Operational risk management · Safety management system

1 Introduction

Human error can be traced to approximately 80% of major Federal Aviation Regulation (FAR) 121 Category aviation accidents in the United States. Of that 80%, up to 10% are caused by human error in aviation maintenance, which is accompanied with a 6.5 times greater chance for disaster [1]. As a result, the Federal Aviation Administration (FAA) is keen on reducing the percentage of accidents caused by human errors related to aviation maintenance. This motivation is further fueled by the projected growth of the aviation industry in the US over the next 25 years. With growth comes additional aircraft, and subsequently the maintenance that will be needed to keep them in the sky. With an increase in maintenance, comes a higher chance for human error within the aviation maintenance environment; while the percentage may stay the same, the pool from which that number is derived, is much larger. The FAA's current strategy to reduce the prevalence of human error in aviation maintenance for FAR 121 operations comes in the form of an internationally acclaimed safety system initiated over the past

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decade by the International Civil Aviation Organization (ICAO); Safety Management Systems (SMS). Although many elements of SMS have been used for decades, overall, it presents a model which identifies certain elements that are mandatory and essential for a successful safety program. These elements are shown in Fig. 1. [2] and represent the 4 supporting legs of the SMS table; Risk Management, Safety Assurance, Safety Policy and Safety Promotion. The SMS table top illustrates the fact that all elements must work together.

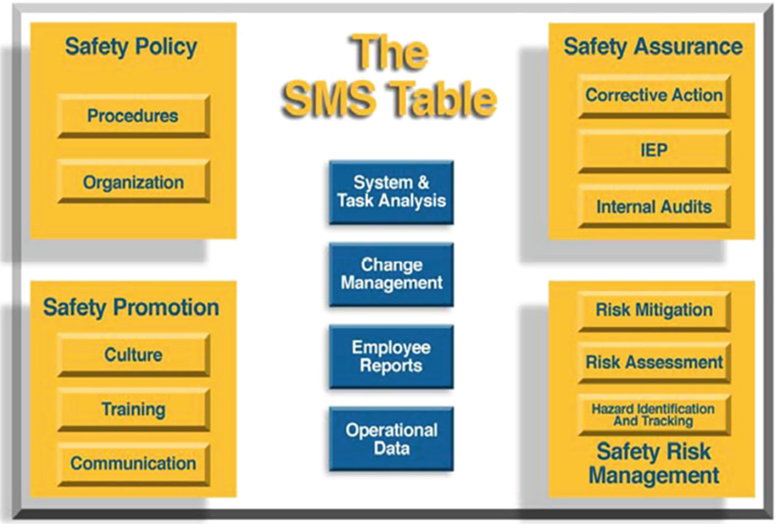

Fig. 1. The SMS Table [2]

SMS Elements. In Fig. 1, the top view of the SMS table can be clearly seen, with the basic requirements for each of the 4 table legs. The upper left corner highlights the important components of the Safety Policy leg via formal procedures, along with how the organization chooses to enforce such procedures. In aviation maintenance, a clear set of safety procedures would be required, along with identified organizational authorities to support the enforcement of safety responsibilities. The upper right corner features the Safety Assurance leg, which emphasizes the handling and tracking of hazards and corrective actions. This also includes having a reporting system to manage and track audits. For the Safety Assurance leg to be successful in an aviation maintenance environment, the anonymity of reporters would be essential. The lower left hand corner, Safety Promotion, represents how the maintenance organization will carry out the SMS system through the development of a safety culture, which in maintenance, would stem from open communication and training. The Risk Management leg in the lower right-hand corner illustrates the importance of risk management via the three required steps of; Hazard Identification, Risk Assessment and Risk Mitigation.

The FAA Mandates SMS in All FAR 121 Operations by March, 2018. Given the fact that the 4 SMS elements work so well together, the FAA has now mandated the use of SMS for all FAR 121 Operators in the United States by March, 2018. This includes FAR 121 maintenance operations that maintain those FAR 121 Operators' aircraft. The use of SMS by FAR 121 Operators can only enhance the safety, however, the overall effect on aviation maintenance operations will remain to be seen. Despite the success of SMS, there are potential issues that could hinder its implementation into aviation maintenance; culture, cost, and practical application. A shift in the safety culture poses significant challenges. The fast pace and unique stressors found in this environment make the implementation of any change difficult. Maintenance is a continuous process. Additionally, the inclusion of a new process will not come without the burden of training, design and implementation costs. The third obstacle would be to ensure all the legs of the SMS Table are carried out as intended. In large FAR 121 aviation maintenance organizations, the concern would be doing the four SMS table legs correctly and then ensuring they are being carried out on a day to day basis. For smaller FAR 121 maintenance operations, and eventually even smaller FAR 135 aviation maintenance operations, attempting to execute the 4 table legs of the SMS without the burden of excessive work, cost, and effort will be difficult. A solution to this issue would be to streamline the process and tailor the four SMS legs to fit the realistic needs of that aviation maintenance organization. The FAA is currently promoting this tailoring philosophy through their SMS training program as a way to address implementation issues. Tailoring the four legs would also allow aviation maintenance organizations to place additional emphasis on human factors, thus mitigating human error and reducing the prevalence of aviation maintenance related accidents.

The SMS Program is Centered Around Risk Management Not Human Factors. One problem with implementing SMS into aviation maintenance operations is the unavoidable risk of human error. Although the SMS is centered on a strong Risk Management Program, it is not the best tool when used independently to analyze and then address the specific human factors that contribute to human error. A closer look at Fig. 1. reveals that the most important leg of the SMS table is the 'Safety Risk Management' leg. As such, it is in the principles of modern risk management that the SMS program was founded on. Within this model is a well-tested, safety process that monitors and contributes to safety, as evidenced by its global use and endorsements by ICAO and the FAA. The Risk Management Process is clearly an effective approach to managing risk. It has proven itself successful over the past 40 years by NASA and the United States military aviation community. In the last 20 years, the entire United States Department of Defense has adopted it. The Risk Management Process consists of 5 important steps as follows: Identify the Hazard, Assess the Risk related to the Hazard, Create a Mitigation Strategy, Implement that Strategy and Assess and Evaluate the process to make changes of improvement.

SMS and Risk Management. At the heart of using the Risk Management Process is the simplified Risk Assessment Matrix. One of the biggest reasons for the success of the Risk Management Process is its ability to identify a hazard and take it through a successful mitigation process, which has been proven it its nearly 40 year track record. Even more important is the fact that within the process it has the ability to rate the hazard, through accurate probability, on its level of danger over time, through a standardized scale. It has become a tool for managers to critically analyze hazards, identify which of those are most critical and must be addressed immediately, and those that can be dealt with at a later time. The other advantage of the hazard rating system is that it can be used operationally, on the spot. As a hazard is identified, it can then be quickly analyzed through a standardized matrix, similar to the one used by the United States Marine Corps in Fig. 2 [3]. By using the Risk Assessment Matrix, any individual in an operational organization can quickly rate the severity of a hazard, the probability of it occurring, and then calculate the hazard's risk assessment. By having the risk level analyzed, it allows managers or other personnel to assess the severity of the risk and determine an appropriate course of action.

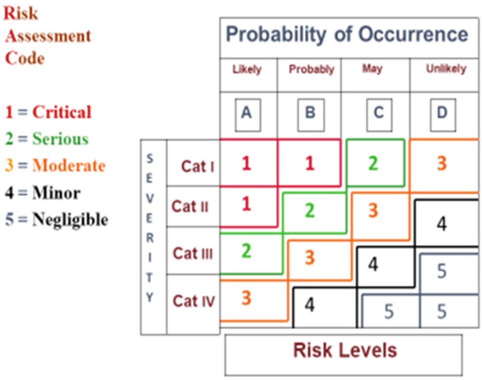

Fig. 2. Risk assessment management matrix [3]

Human Factors to Analyze Human Error is also Needed in Maintenance. Although the Risk Management process has proven effective at identifying and assessing hazards which pose risks, many aviation maintenance hazards are due to human factors, which ultimately result with errors in maintenance. Additionally, many of these errors are not found in isolation; they are multiple human factors, when linked together result with human error, ultimately working against safe maintenance practices. Numerous research studies have uncovered human error trends in aviation maintenance by examining years of accident investigation data related to aviation maintenance in FAR 121 Operations. According to Rankin [4], the breakdown of these accidents is 20% mechanical failure and 80% human error (to include: aircrew, air traffic control and maintenance personnel). Additionally, Graeber and Marx [5] indicate that human error has led to improper aviation maintenance, contributing to 12% of major aircraft accidents (for FAR 121 Operations) and 50% of propulsion system malfunctions that ultimately resulted in flight postponements and terminations. While 12% may not seem significant, for aviation maintenance operations, this percentage is alarming. The potential for human error in maintenance to directly contribute to an aviation accident, including loss of human life along and the destruction of an aircraft, is evident. Accidents such as these come with a tremendous price tag; a maintenance malpractice suit could easily bankrupt a major carrier. Commercial flight operations in the United States have been operating at the highest levels of safety in the past decade, however, a flurry aviation maintenance mistakes, or substantial increase in the demand for air travel, could quickly change that. According to Hobbs [6], human error in aircraft maintenance not only presents a dangerous hazard to flight safety, but it has the potential to generate significant financial costs related to flight postponements, terminations, alterations, and other schedule interruptions.

Identifying the Human Factors that Contribute to Human Error. The issue with human error in aviation maintenance is not that these dangers are not known or that the industry does not want to eradicate this danger from commercial flight. Instead, the problem is how to identify and control the myriad of human factors issues in maintenance, many of which tend to combine together, as if part of the procedure. When this occurs, the chain of errors which results can be disastrous. Aircrew and air traffic control research has helped drive major improvements in the flight process. Technological innovations have made considerable aviation safety improvements, resulting in a reduction of human error and a 40% reduction in aircrew related accidents between 1983 and 2002 [7]. Over the last 30 years, such successful processes like Advanced Crew Resource Management and technology improvements like Ground Proximity Warning System (GPWS), Terrain Collision Avoidance System (TCAS) and Onboard Weather Radar, have vastly reduced human error in the United States in the aircrew and controller environment. But what can be done to likewise reduce human error in maintenance?

Understanding Human Error in Aviation Maintenance through Human Factors Research. Looking closer at the research, human error in aviation maintenance tells of a complex story with no easy solutions. Critical evidence from research investigations performed in aviation maintenance found that 34% of regular maintenance tasks were performed incorrectly [8]. Further analysis shows that 38% of human error in aviation maintenance was related to aviation maintenance technical manuals that were used to perform maintenance procedures [9]. In the same study, the researchers were able to break the 38% procedural error from technical manuals down to: omitted information (48%), improper information (19%), difficulty interpreting data (19%), and inconsistent information (14%). The investigation also noted that 28% of the error resulted from the inability of aircraft maintainers to read, understand, or follow the technical manual appropriately. Graeber and Marx [10] noted that a significant number FAR 121 Operations accidents were caused by maintenance and concluded that these types of accidents were also categorized in causation by: omissions (56%), inadequate installations (30%), and incorrect parts (8%).

Human Factors that Influence Human Error in Aviation Maintenance. After reviewing much of the research on aviation maintenance-related accidents, it is clear that much of the human error is rooted in the conduct of maintenance itself; the technician either does the task correctly or incorrectly. This begs the question, why is this occurring? Marais and Robichaud [1] have found the environment surrounding maintenance procedures plays a crucial role in causing maintenance errors. Much of this is due to the fact that 90% of maintenance inspection procedures are visual, and often involve a critical sequence of procedures, which must be followed exactly. The investigation found that if aviation maintenance technicians (AMTs) were not provided the appropriate conditions (such as proper lighting), numerous defects in the maintenance process may be missed, resulting in human error and compromised safety. Other research completed by Transport Canada found similar environmental conditions, as well as other contributing factors, which could cause an aviation maintainer to err in their task. During the 1980's, Transport Canada did a great deal of research on human error in aviation maintenance, which ultimately resulted in the formation of the 'Dirty Dozen', the twelve most common contributing human factors that influence human error and contribute to aviation maintenance accidents.

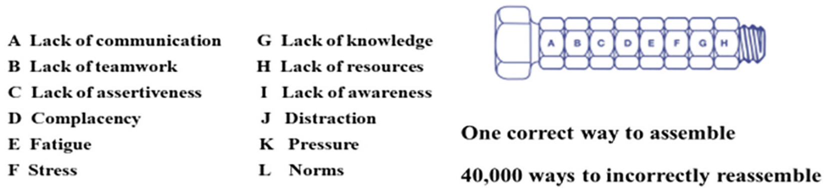

Fig. 3. The dirty dozen and 40,000 ways to make an aircraft maintenance error [11].

Effects of Human Factors like the Dirty Dozen on Aviation Maintenance Human Error. The illustration in Fig. 3 shows the Dirty Dozen next to a bolt with several nuts on it [11]. It represents an aviation maintenance procedure, making the point that there is only one way to procedurally take the bolts off the nut (one by one). Putting the nuts back on, however, could be done in 40,000 different ways. Each of the nuts could be associated with one of the Dirty Dozen. For example, the nuts should procedurally go back on the bolt in order from A-H, but due to lack of communication, nut A was set aside and nut B was placed on first. Due to lack of teamwork, as the maintainer was working alone, nut B was not placed perfectly to the top of the bolt. Due to lack of assertiveness the oncoming maintainer in the new shift placed nut C behind nut B even though he could see that nut B was possibly not perfectly flush, but was confident that with nut C tight behind it, there would be no problem. As this maintenance procedure continues through the completion of nut H, the human factors associated with the event are compounding, thus increasing the possibility of a human error, and potentially an aviation mishap. The point of the lesson is that any of the Dirty Dozen, along with many other human factors variables, can interfere with aviation maintenance personnel while working, causing any number of maintenance procedures to be completed incorrectly.

The PEAR Method of Human Factors Analysis for Aviation Maintenance. To help recognize the danger of potential human factors variables which can contribute to or cause dangerous levels of miscues in aviation maintenance, the FAA devised a maintenance human factors analysis method, in the form of an acronym called the PEAR method [12]. The "P" in the PEAR Model stands for people and all the possible human factors that can affect people, including physiological, psychological, and ergonomic factors that maintainers encounter in their daily tasks. The "E" in the PEAR Model stands for the environment that surrounds the maintainer. The environment includes elements such as temperature and humidity, the amount of light available, the air that is being breathed and noise. Other factors such as pressure to complete a task by a manager is also considered environmental, as is fatigue encountered during the night shift. The "A" in the PEAR model stands for the actions that the maintainer did or did not perform during the conduct of maintenance. Actions become important during the analysis phase given that they relate directly to procedural human error, which has been identified as the leading cause of maintenance aviation accidents. The last letter in the PEAR Model is "R", which stands for maintenance resources. Was proper maintenance equipment and/or tools utilized to complete the task? Most importantly, were the proper parts distributed for the assigned task? Each of the PEAR letters are important because they truly identify relevant human factors which can be linked to human error in maintenance. The issue, however, with the PEAR method, is that it does not optimally address human error. Should the PEAR be used after an accident or incident occurs or should it be used strongly in a prevention role as well? The new SMS system is based on a proactive and preventative safety stance. Perhaps now is the time to introduce a new model for human factors in maintenance using the SMS principles to proactively prevent human error in maintenance by including a form of the PEAR method within an SMS program?

The REPAIRER Reporting System. Such a model would seem difficult to design and achieve. However, if the foundation of the design is centered on streamlining and tailoring the SMS model for aviation maintenance purposes so that it can be used efficiently, a new model is feasible. By combining human factors and risk management to an SMS reporting system, both safety and efficiency can be achieved. Utilizing an existing acronym already familiar to maintenance personnel (PEAR), the REPAIRER reporting system is an appropriate place to begin [13].

The First "R" is all about Rating and Reporting a Hazard. The first "R" in the REPAIRER model stands for rating and reporting a hazard. In this first step, two critical elements of the SMS are immediately incorporated. A hazard is identified, rated and will be anonymously reported by anyone in the maintenance organization. The identification of a hazard and rating it are foundational SMS Risk Management steps, which can be found in the SMS Risk Management table leg. After the hazard is identified, utilizing a Risk Management Matrix can help managers to quickly assess how dangerous a potential hazard is by giving it a risk assessment value. Hazards with the highest risk assessment ratings should be given priority, as opposed to those with lower risk assessment ratings. Reporting the hazard is another SMS foundational step required under the Safety Assurance table leg. In essence, REPAIRER is first and foremost a reporting system to improve safety and gain opportunities for efficiency in a maintenance organization.

The 'EPAIR' in REPAIRER Becomes the Human Factors Analysis of the Hazard. Unlike other SMS reporting systems that simply identify and rate a hazard, REPAIRER requires human factors data to be reported, and is represented in the 'EPAIR' of the REPAIRER acronym. This is the opportunity for ideas found in the original PEAR method to be used in the SMS format, as a human factors analysis maintenance tool. The 'EPAIR' has now become a modified PEAR model within the

REPAIRER system to analyze potential human factors related to the hazard. The "E" stands for the environment that the hazard occurs in. Details of the environment need to be supplied by the person filling out the REPAIRER report. This includes a physical overview of the environment such as lighting and temperature, but also what was occurring within the organizational environment during the time of the hazard. The "P" stands for the people involved. This includes deficient qualifications and any training required to conduct the task. Additionally, any physical, physiological or psychological issues deemed relevant should be included in the report as well. The "A" in the REPAIRER method stands for the actions of the people involved. Because maintenance research points toward procedural problems, in terms of human error in causing 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 REPAIRER method stands for the investigation of the proper procedures associated with conducting the maintenance action, noting any shortfalls, as implied or found during the "A" step. This step is critical; it is imperative to know exactly how the incorrect maintenance action was performed, but also how it should have been done correctly. Additionally, there is a chance that the current procedure is either unsafe or inefficient, and therefore must be amended. The next letter in the REPAIRER model is the second "R" for the resources that were required to do the job. If the resources required to complete the maintenance task were inadequate in any way, they need to be reported here.

Creating a Mitigation Strategy and Reevaluating it. Once the Hazard has been identified, rated, and analyzed for potential human factors, it then becomes important to complete the next task; the recommended solution using the human factors analysis. With a recommendation in place, it must be continually reevaluated to ensure both safety and efficiency are achieved. Both are critical steps in completing the SMS requirement, given that the mitigation strategy falls under the Risk Management table leg. The reevaluation falls under the Safety Assurance leg. The second "E" in the REPAIRER model is associated with executing mitigation strategies for the identified hazard. At a minimum, the person or persons filling out the report need to make a recommendation. By doing so, the person reporting the hazard will have an incentive to do so, as they will feel part of the solution. The last letter of the REPAIRER model is the third "R" which stands for reevaluating the mitigation strategies after a period of time, to ensure they are working. Whether the mitigation strategy was created by the person generating the report or by others within the organization, it can never be taken for granted that the mitigation strategy is working in the maintenance environment. The final "R" of reevaluation requires some form of an audit or inspection to reassess the significance of the hazard, once the mitigation strategy is in place. If the mitigation strategy is working, no further action is needed. However, if the mitigation strategy needs to be changed or adjusted, this is the opportunity to do so. Once the strategy has been reevaluated, and is deemed completed, no further action is needed. The proper completion of the last "R" is paramount to concluding the REPAIRER process.

Application. With the REPAIRER Reporting System created, it is now essential to implement this system in an effort to determine the extent to which safety and efficiency in an aviation maintenance environment could be improved. First, the policy pillar of SMS would be addressed through the identification of the REPAIRER procedures. This would be supported via a departmental authority, such as the Quality Assurance Manager or the Director of Maintenance. Both of these positions provide the appropriate resources as well as authority measures to clearly identify safety policy procedures. Included in the policy would be methods for anonymous reporting. This is an essential component in the successful implementation of the REPAIRER reporting system; for doing so would allow employees at all levels in the organization to report a potential safety hazard, without risk of retribution. One way this could be accomplished would be via a mobile reporting app, many of which are confidential and anonymous; however, the REPAIRER system allows the freedom for organizational authorities to make such decisions as appropriate and fiscally feasible.

After the procedures are written, the SMS Promotion table leg would then need to be addressed. As with any SMS, in order for the policy leg to be supported, it needs adequate support from leadership. The end-state goal would be to create a culture of safety and open reporting, which is founded on the REPAIRER strategy. Given that the strategy is rooted in SMS policies and procedures, which most aviation maintenance organizations currently have in place, minimal training would be needed. After reviewing current safety policies, gaps could be identified between current procedures and the REPAIRER method. Once identified, short videos which explained the new, additional steps could be constructed. The videos would be 2–3 min in length and include employees from all levels of the organization. The videos could be accessed through mobile devices, which would have minimal impacts on workload. Each step could be completed separately, over the course of a week or two. At the end of the training period, a summary video would review the pertinent steps of the REPAIRER method, given again by someone in the organization that employees could relate to. However, this could not be completed without buy-in from leadership at every level in the organization. All managers and supervisors must relate the value created by the REPAIRER strategy to those that must enforce it on a daily basis. This could be done visually or virtually via white boards in the hangar or on the organization's website. In doing so, the technicians could see and track how their daily decisions impact overall safety, the number of accidents, and the fiscal repercussions that result.

Once these last two legs of the SMS table are in place, it would then be of utmost importance to test the REPAIRER Reporting System to determine the extent to which this system enhanced safety and efficiency, while maintaining fiscal constraints. An optimal organization for which the REPAIRER Reporting System to be tested would be small to medium sized aviation maintenance organizations which operated under FAA Part 121 authority.

References

1. Marais, K.B., Robichaud, M.R.: Analysis of trends in aviation maintenance risk: an empirical approach. Reliab. Eng. Syst. Saf. **106**, 104–118 (2012)
2. The MITRE Corporation. All Rights Reserved: The Safety Management System (Top View). Approved for Public Release; Distribution Unlimited, 06-1512 (2006)
3. United States Marine Corps: Risk Management Assessment Matrix. Marine Corps Order 3500.27c, 15 (2014)

4. Rankin, W.: MEDA investigation process. Aero Mag. Q. **2**, 14–21 (2007)
5. Graeber, R.C., Marx, D.A.: Human error in aircraft maintenance. In: Johnston, N., McDonald, N., Fuller, R. (eds.) Aviation Psychology in Practice, pp. 87–104. Averbury, Aldershot (1994)
6. Hobbs, A.: An Overview of Human Factors in Aviation Maintenance. ATSB Transport Safety Report (2008)
7. Baker, S.P., Qiang, Y., Rebok, G.W., Guohua, L.: Pilot error in air carrier mishaps: longitudinal trends among 558 reports, 1983–2002. Aviat. Space Environ. Med. **79**(1), 2–6 (2008)
8. McDonald, N., Corrigan, S., Daly, C., Cromie, S.: Safety management system and safety culture in aircraft maintenance organizations. Saf. Sci. **34**, 151–176 (2000)
9. Chaparro, A., Groff, L., Chaparro, B., Scarlett, D.: Survey of Aviation Technical Manuals: Phase 2 Report. User Evaluation of Maintenance Documents (Technical report No. DOT/FAA/AR-02/34), Washington, DC Federal Aviation Administration, Office of Aviation Research (2002)
10. Graeber, R.C., Marx, D.A.: Reducing human error in aircraft maintenance operations. In: Proceedings of the Flight Safety Foundation International Federation of Airworthiness 46th Annual International Air Safety Seminar (1994)
11. Dupont, G.: Human Performance Factors for Elementary Work and Servicing. Transport Canada, TC14175, pp. 1–27 (1993)
12. Johnson, W.B., Maddox, M.E.: A model to explain human factors in aviation maintenance. Avionics News 1–4 (2007)
13. Miller, M.D.: The Repairer Reporting system Strategy for Aviation Maintenance: Integrating Human Factors and Risk Management into Aviation Maintenance for SMS Compliance. Presentation to FAA Aviation Maintenance Mega Conference Honolulu (2016)