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Risk Matrix Approach to Human Factors in Aircraft Maintenance Organization

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Risk Matrix Approach to Human Factors in Aircraft Maintenance Organization

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Abstract

Contemporary management and strategy requires the optimization of ingredient factors such as human resources, systems, operations and equipments. Applying System Approach in management and strategy, human error has considerable potential to change results as airworthiness in aircraft maintenance organisations (AMOs). Key challenge for AMO's management is to create opportunities for minimization of human factor based error, and this consists the main aim of this research. Maintenance errors negatively affect flight safety and are very costly for the aviation sector. The investigation process of the error for managing situational awareness is critical for AMOs. In this process, it is very important to determine the factors contributing to the aircraft maintenance technician (AMT) error and corrective actions related to factors that contributed to error must be taken by AMOs. In this study, "The Dirty Dozen" factors, known as the 12 most common causes of a maintenance error by AMT, are designed as a risk matrix, with application in Anadolu University's AMO, in Turkey. High ranked managers, a focus group and a workshop are used to collect the study's data. Owing to risk matrix, managers make a more informed decision about their options, sharing corporate sources in a timely manner. Thus, the objective of this study is to determine factors of AMT error with high risk, for managing situational awareness. The results of this study are intended to constitute a guide for AMOs to manage situational awareness about risk factors and to take corrective and preventive actions for their maintenance operations, based on the relevant risk matrix. It is believed that this study contribute to awareness for similar practices, as AMOs have common characteristics.

Keywords: Aircraft Maintenance Technician, human error, situational awareness, Aircraft Maintenance Organization (AMO) management, Dirty Dozen.

Introduction

Human factors of aviation maintenance focus on the employee who perform the work and address physical, physiological, psychological, and psychosocial issues. Management must focus on individuals, their physical capabilities, and the factors that affect them. It also should consider their mental state, cognitive capacity, and conditions that may affect their interaction with others (FAA, n.d.).

In the aviation sector, aircraft maintenance staff is the most important, having a central part of the aeroplane maintenance system and ensures safety of the next flight of the aeroplane (Kucuk Yılmaz and Yazgan, *in press*). A manufactured aircraft is produced and certificated to meet airworthiness and safety requirements when delivered to the operator. The main purpose of the maintenance is to prevent potential insecurities by keeping the performance and reliability of the aeroplane within the specified design limits after delivery to the operator. While there are many different definitions for the aircraft maintenance, it can be described as any revision activities, modification activities, repairing activities, preventive activities, checking activities, and service activities to keep it airworthy during the period from the manufacturing of the aeroplane until its discontinuation (slonder.tripod.com, 2017).

Literature is rich with theories, concepts, and models discussing human reliability and associated human error causal factors that always set the scene for incidents and accidents to occur within safety-critical HMI (Human-Machine Interaction) systems (Rashid, 2010). We reviewed some of the techniques and approaches that have been proposed and applied to reduce the probability of human error in the aviation maintenance environment. This review considers the broad categories of: (1) training, (2) job design and organizational considerations, (3) workspace and ambient environment design, (4) task equipment and information design, and (5) automation. Recent efforts in training focus on enhancing teamwork in aviation maintenance and inspection. The success of Crew Resource Management (CRM) in improving team performance on the commercial flight deck, provides a model for improving collaborative work in the inspection/ maintenance environment. The Federal Aviation Administration (FAA) of USA (the national authority with powers to regulate all aspects of civil aviation) has proposed to extent the CRM approach to Maintenance Resource Management (MRM), or Technician Resource Management (TRM), to encourage teamwork and effective problem solving in maintenance crews (Latorella and Prabhu, 2000). One of the early MRM training programmes was developed by Gordon Dupont for Transport Canada. It introduced *"The Dirty Dozen"*, which are the 12 most common causes of a maintenance employee to make an error (maintenance error) (CAA, 2002; Dupont, 1997). Due to a large number of maintenance-related aviation accidents and incidents that occurred in the late 1980s and early 1990s, Transport Canada identified twelve human factors that degrade people's ability to perform effectively and safely, which could lead to maintenance errors. These twelve factors, known as the "dirty dozen," were eventually adopted by the aviation industry as a straightforward means to identify human error in maintenance. It is important to know "the dirty dozen", to recognize their symptoms, and most importantly, to avoid or contain errors produced by them. Understanding the interaction between organizational, work group, and individual factors that may lead to errors and accidents, AMTs can learn to prevent or manage them proactively in the future (FAA, n.d.).

The "dirty dozen" factors have long since been identified and can be seen from the examples of accidents contributed. It is imperative that maintenance organizations inculcate a working environment that face these factors holistically. Stress and many more factors can affect a maintenance technician's performance. Yazgan and Kavsaoğlu (2017) have examined aviation accidents, for which stress is a causal or contributory factor which is one of the "dirty dozen".

The implementation of this concept was examined in the Anadolu University's AMO in Eskisehir, Turkey. Based on the key informants with a rich knowledge of the subject, focus group and one dedicated workshop the study's data were collected. The implementation of the "dirty dozen" concept in the specific organisation takes place for the first time and useful results were generated.

Methodology

In this study, risk assessment are performed for these 12 ("dirty dozen") factors affecting AMT error during maintenance operations. These risk factors are prioritized and much effort has spent to face them by the Anadolu University's AMO in Eskisehir, Turkey. Anadolu University is the owner and operator of Hasan Polatkan Airport (AOE) and this is the first licensed University Airport, since 2007. AOE can serve international and domestic operations. Anadolu University's operates an AMO which has approved by Directorate of General Civil Aviation of Turkey, which is the national civil aviation authority responsible for AMOs authorization (certification for part 145 which applies to the authorization of AMOs). Anadolu University's AMO has one hangar. In this AMO, Cessna 172, Socata TB20 and Beechcraft C90 aircrafts are maintained by certificated maintenance technicians.

Assessments of eight (8) specialists, high ranked managers from the Anadolu University's AMO were used in the current study. In particular, two (2) high ranked managers of Faculty of Aeronautics and Astronautics in Anadolu University and its managers of the Quality Department of AMO, were participated in the current study. In addition, a focus group - consisting by Professors and students were the study is piloted and the findings discussed - was used. A one-day workshop was organised to discuss the study, its findings and ways to improve the AMOs operation. The combination of these three sources contributed to the study's quality, achieving triangulation which generates "more objective and valid results" (Jonsen and Jehn, 2009: 125).

The participants of the study had a rich knowledge of the subject and high experience.

Literature Review

In this part of the study the "dirty dozen" factors and risk management and risk assessment concepts will be presented.

"Dirty Dozen" and Aircraft Maintenance Technician (AMT)

The thorough analysis of the 'human factor' can generate the twelve factors ("dirty dozen") that may cause an error for AMT and these are the following (Dupont, 1997; FAA, n.d.):

1. *Lack of communication*: Communication occurs between the AMT and many others (i.e., management, pilots, parts suppliers, aircraft servicers). Lack of communication can be in the form of verbal or written or a combination of the two. This can lead to the potential for misunderstanding or omission. But communication between AMTs may be the most important of all. Lack of communication between technicians could lead to a maintenance error and may result in an aircraft accident. This is especially true during procedures where more than one technician performs the work on the aircraft. It is critical that accurate, complete information be exchanged to ensure that all work is completed without any step being omitted. Knowledge and speculation about a task must be clarified and not confused.
2. *Complacency*: Complacency is an insidious cause which with the constant repetition of many maintenance inspections can cause or contribute to an error. To combat complacency, a technician must be efficiently and sufficiently trained to identify the faults in the inspection items in the first place. He or she must stay mentally engaged in the task being performed. All inspection items must be treated with equal importance, and it must never be assumed that an item is acceptable when it has not been inspected. A technician should never sign for any work that has not been performed.
3. *Lack of knowledge*: In this ever changing world, lack of knowledge is a common cause of an error in judgment. When coupled with the "Can-Do" attitude of most maintenance personnel, it becomes even more probable. Differences in technology between various aircrafts types and procedures that followed also make it challenging to have the required knowledge to perform an airworthy maintenance.
4. *Distraction*: This cause is responsible for about 15% of all maintenance errors. One leaves a task (both physically and/or mentally) for any reason and thinking other things (such as family issues) with negative consequences for his/her task. Distractions can be mental or physical in nature. They can occur when the work is located on the aircraft or in the hangar. They can also occur in the mind of a technician independent of the work environment. Something as simple as a cell phone call or a new

aircraft being pushed into the hangar can disrupt the technician's concentration on a job.

5. *Lack of teamwork*: This cause is often tied in with lack of communication but can be responsible for major errors. With maintenance often involving a multitude of workers, good teamwork becomes essential. Closely related to lack of communication, teamwork is required in aviation maintenance in many instances. Sharing of knowledge between technicians, coordinating maintenance functions, turning work over from shift to shift, and working with flight personnel to troubleshoot and test aircraft all are better executed in an atmosphere of teamwork.
6. *Fatigue*: Fatigue is a very insidious cause because, until it becomes extreme, the person is usually unaware that he/she is fatigued. They are even less aware of what the effects of fatigue are. Fatigue is a major human factor that has contributed to many maintenance errors resulting in accidents. Fatigue can be mental or physical in nature. Emotional fatigue also exists and effects mental and physical performance. A person is said to be fatigued when a reduction or impairment in any of the following occurs: cognitive ability, decision-making, reaction time, coordination, speed, strength, and balance.
7. *Lack of resources*: No matter who the maintainer works for, there are times when there is a lack of resources and a decision must be made between ground the aircraft or let it go. The average maintainer is a "Can-Do" type of person and takes great personal pride in repairing an aircraft. Thus the decision to be made can be difficult. A lack of resources can interfere with one's ability to complete a task because there is a lack of supply and support. Low quality products also affect one's ability to complete a task. Aviation maintenance demands proper tools and parts to maintain a fleet of aircrafts. Any lack of resources to safely carry out a maintenance task can cause both non-fatal and fatal accidents.
8. *Pressure*: Few industries have more constant pressure to see a task completed. The secret is the ability to recognize when this pressure becomes excessive or unrealistic. Aviation maintenance tasks require individuals to perform in an environment with constant pressure to do things better and faster without making mistakes and letting things fall through the cracks. Unfortunately, these types of job pressures can affect the capabilities of maintenance workers to get the job done right.
9. *Lack of assertiveness*: The average AMT is not an assertive person. However, there may come a time when something is not right and he/she will have to be assertive in order to ensure the problem is not overlooked. Assertiveness is the ability to express your feelings, opinions, beliefs, and needs in a positive, productive manner and should not be confused with being aggressive. It is important for AMTs to be assertive when it pertains to aviation repair rather than choosing or not being allowed to voice their concerns and opinions.
10. *Stress*: Stress is a normal part of everyday life until it becomes excessive. The secret is to be able to recognize when it is becoming excessive.

Aviation maintenance is a stressful task due to many factors. Aircraft must be functional and flying in order for airlines to make money, which means that maintenance must be completed within a short timeframe to avoid flight delays and cancellations. Fast-paced technology that is always changing can add stress to technicians. This demands that AMTs stay trained on the latest equipment. Other stressors include working in dark, tight spaces, lack of resources to get the repair done correctly, and long hours.

11. *Lack of awareness*: This often occurs to very experienced maintenance personnel who fail to think fully about the possible consequences of work they are doing. Although manuals continuous updated sometimes do not cover the failure and new cases and the common sense and experience can solve these new problems. In aviation maintenance, it is not unusual to perform the same maintenance tasks repeatedly. After completing the same task multiple times, it is easy for technicians to become less vigilant and develop a lack of awareness for what they are doing and what is around them.
12. *Norms*: This last cause is a powerful one. Most people want to be considered one of the crowd and norms develop within such a group dictates how they behave. Norms are short for "normal," or the way things are normally done. They are unwritten rules that are followed or tolerated by most organizations. Negative norms can detract from the established safety standard and may cause an accident to occur. Norms are usually developed to solve problems that have ambiguous solutions. Norms have been identified as one of the dirty dozen in aviation maintenance and a great deal of anecdotal evidence points to the use of unsafe norms. The effect of unsafe norms may range from the relatively benign, such as determining accepted meeting times, to the inherently unsafe, such as signing off on incomplete maintenance tasks.

The concept of "dirty dozen" has used widely in the literature mainly shedding light in the maintenance issues and in particular in errors avoidance (Jablonski, 2018; Miller and Mrusek, 2018; Patankor and Taylor, 2017; Schoning and Ersen Comert, 2018; Thompson, 2018).

Dhillon, 1986 (cited in Noroozi et al., 2013) mentioned the reasons for errors in maintenance organisations and these can be the work layout, poorly written maintenance procedures, complex maintenance tasks, harsh environments (i.e. temperature, humidity, noise), fatigue, outdated maintenance manuals and inadequate training and expert.

Risk Management

Human factors and risk are interrelated issues, influencing the operation of organizations and are presented below.

Risk contains all the actions in a daily operation of organizations and management should handle it with extra care. Risk often appears with incapability to tackle a specific issue. Any danger or its contributing factors constitute risk in association with negative consequences or unexpected outcomes. A quantitative or qualitative analysis is required to assess the risks as well as the physical, social, economic and environmental causes and effects in detail (Uluturk, 2006).

Leveson (2015) defines risk as the severity of an event combined with the probability or likelihood of the occurrence of that event. Risk can be expressed by probability multiplied by consequences. Although the use of probabilities can generate poor predictions as these are based on conditional specific background knowledge and does not necessarily provide a sufficiently informative picture of the risk. The risk can be described by: injury and accident statistics, risk indicators based on hazard situations, barrier indicators, risk analyses, interviews, surveys of co-workers, and expert groups. The risk analysis is necessary as it provides a risk picture for a given activity or a given system and through this, consists a basis for decision making concerning the selection of solutions and measures. The objective of the analysis is to identify the important contributors to risk and describing the effect of possible measures on the risk. Although, it is difficult to include all factors contributing to risk, including human performance, organizational, management and social factors, to incorporate human error and complex decision making and to capture the non-linear dynamics of interactions among components (Aven, 2008). Therefore, the use of the right methods that the literature suggests and are presented below is necessary.

Risk management includes all the necessary measures and activities which are placed on many levels and carried out to manage risk and assist organization to achieve its goals and vision. Risk management processes need formal guidelines or criteria (ie risk acceptance criteria and cost-effectiveness indices) to simplify the decision-making. The risk management task is divided into three main categories: a) strategic risk, b) financial risk, c) operational risk. Some significant issues to ensure success are: i) establishment of a strategy for risk management, ii) establishment of a risk management process for the firm (formal processes and routines), iii) establishment of management structures (roles and responsibilities), iv) implementation of analyses and support systems (risk analysis tools, recording systems for occurrences of various types of events etc.), v) communication, training and development of risk management culture (Aven, 2008).

According to Konukcu (2006), the process in managing risks should follow the risk identification, analysis, planning and so on. In that study, analytical techniques were identified to maintain and enhance the reliability and safety in aeronautical systems, called Risk Ranking and Analytical Hierarchy Process (AHP).

According to Aven (2008), risk analysis is a useful decision support tool regarding choice of solutions and measures. Risk analysis has an important role in risk management and can follow a basic structure independently of its area of application. Risk assessment can include both the risk analysis and risk evaluation. Risk assessment is followed by risk treatment and represents the process and implementation of measures to modify risk, including tools to avoid, optimize, transfer and retain risk. The risk picture is established based on the cause analysis and the consequence analysis. Cause analysis monitors what is needed for the initiating events to occur. Consequence analysis for each initiating event is carried out, addressing the possible consequences the event can lead to, such as financial losses, loss of lives and environmental damage. The selection of analysis method depends on the phase, ease access to information, the system's significance and its complexity and other factors.

Also, combining the severity of all loss events associated with a system and their estimated future probability or likelihood provides a metric for risk (Leveson, 2015).

According to Aven (2008), the most basic risk analysis methods are: 1) Coarse risk analysis which provides a crude risk picture, by dividing the analysis subject into sub-elements and then carrying the risk analysis for each of these sub-elements. 2) Job safety analysis which is a simple qualitative risk analysis methodology, usually check-list based and is used to identify hazards that are associated with a work assignment that is to be executed. 3) Failure modes and effects analysis which aims to reveal possible failures and to predict the failure effects on the system as a whole. 4) Hazard and Operability studies which is a qualitative risk analysis technique that is used to identify weaknesses and hazards in a processing facility and is used in the planning phase (design). 5) SWIFT (Structured What – If Technique) which uses the lead question – what if – systematically in order to identify deviations from normal conditions. 6) Fault tree analysis which includes a logical diagram that shows the relation between system failure, i.e. a specific undesirable event and failures of the components of the system. The undesirable event constitutes the top event of the tree and the different component failures constitute the basic events of the tree. 7) Event tree analysis which is used to study the consequences of the initiating event of a bow-tie diagram. The method can be used both quantitatively (the method provides a picture of the possible scenarios) and qualitatively (probabilities are linked to the various event sequences and their consequences). 8) Bayesian networks which consists of events (nodes) and arrows. The arrows show dependencies, i.e. causal connections. Each node can be in various states and the number of states is selected by the risk analyst. 9) Monte Carlo simulation which aims to generate a computer model of the system to be investigated, for example represented as a reliability block diagram, and then to simulate the operation of the system for a specific period of time.

In addition, Aven (2008) pointed out that the use of quantitative analyses should take place with extra care, in particular when cases with large uncertainties are examined and these analyses provide a rather narrow risk picture, through calculated probabilities and expected values. On the other hand, qualitative approaches are appropriate in some case, as a more "broad" risk description is required. These approaches take place when there are different views related to the values to be protected and the priorities to be made.

Leveson (2015) proposes a new and different approach to identify system-specific leading indicators and provides guidance in developing a risk management structure to generate, monitor and use the results. Leading indicators provide important signals about the potential for an accident and it is necessary to define effective and a small number of them in order to identify the increasing risk of an accident. The identification of leading indicators will necessarily be associated with the assumptions about the occurrence of an accident which contain social and managerial issues. If the likelihood is not zero, then the assumption needs to take into account for inclusion in the leading indicator program. Assumptions may provide important information if included in a leading indicator program. Assumptions can be technical (engineering), managerial and organizational. The suggested approach is based on the STAMP (System-Theoretic Accident Model and Processes) model of accident causation. The model includes non-linear, complex causes and indirect relationships and can better handle the levels of complexity and technical innovations, anticipating the risk-related consequences of change and adaptation over time. STAMP supports that accidents occur when safety constraints of the system are violated. The author proposes the use of a new hazard analysis method STPA (System Theoretic Process Analysis) and this can be used to identify safety critical assumptions that can then shape the basis for a leading indicator program. STPA can be implemented in the physical system, management structure and organizational design. The creation and use of effective leading indicators will require ways to control the psychological biases and to take into account organizational culture and politics that influence likelihood and vulnerability. Leading indicators should be integrated into the risk management program, in order to encourage effective action. These leading indicators must be communicated to the appropriate decision makers and detailed action plans for critical scenarios have to develop. Every leading indicator should be show “when and how it will be checked” and must include an action associated with it. Periodically the list of the leading indicators should be revisited and, if necessary, updated. A continuous improvement process should be established. Leading indicators can be similar for different firms only in the case that the hazards, safety constraints, system design and safety control structure are similar. The leading indicators must reflect the specific physical or organizational conditions in which they are implemented.

The risk of an accident to occur is largely related to employees and for this reason is necessary to study human factors. According to Noroozi et al. (2013), the human involvement in all functions, including management and decision-making, makes the human error inevitable. Also, the performance of wrong actions or the lack and the failure to perform a necessary action can lead to human error. Gould and Lovell (2009) pointed out the necessity to identify human errors and particular the potential sources, control and minimize them. The establishment of good operating procedures can prevent major accidents and the objective should be the identification of the most critical of them those that have the largest potential to cause a major accident. According to McSweeney, de Koker and Miller (2008), human error includes the systematic collection and application of information regarding human characteristics and behaviours in order to improve the performance of human-machine systems. Noroozi et al. (2013) pointed out that human error can occur from common mistakes that “are easily identified, diagnosed and general excusable” (p. 251), and the probability of human errors needs to be strictly monitored for its potential impact on system failure and effectively manage and reduce error.

The probability of the harmful event to occur is increased in the cases of complex or infrequently used procedures (Gould and Lovell, 2009) and it is difficult to handle effectively risk in these cases (Leveson, 2015).

The use of risk matrix is useful, providing a better picture of risks and their consequences. Gould and Lovell (2009) and Aven (2008) suggests the establishment of risk matrix which is consisted by the probability and consequence categories for the assessment of each procedure. The matrix is used as a visualization tool when multiple risks have been identified to facilitate comparing the different risks. Risk matrices are also used to help to define which risks need further or more detailed analysis or which given risk is considered broadly acceptable or not acceptable, according to the zone where it is located on the matrix (European Commission, 2010). According to Gould and Lovell (2009) the assessment of human errors should contain the cause of error, the consequence of error and existing controls and recovery actions. The human error analysis increases ownership and general awareness of human error within the organization and confidence in the procedures, making deviations less likely. However, systematic human error analysis is a labour-intensive process and a significant amount of time from specialists and operators is needed. Measures to face risks requires some costs and are against production.. According to Maurino (2000), competition between production and safety goals should be take into account and the optimum performance should be achieved satisfying the safety demands. Maurino (2000) examined how the human factors are related to aviation safety pointed out the need to understand the processes which are affected by contextual constraints and cultural factors, which in turn impact individual and organizational performance. Safety and risk and the meaning of the numbers are issues affected by common group history and experience, consequently these are influenced by national and organizational culture. Also, all the components of the aviation system should be considered and no those which are related to safety breakdowns.

Massaiu (2009) pointed out the need of integration of human factors into risk analysis, as the first contribute to industrial safety. Also, accident models determine what hazards to consider and how to do it and they direct at where to look and what categories can be used in order to efficiently handle the causes of accidents. Regarding accident models the author suggested i) the incident analysis which include factors involved in accidents, to extract and monitor trends over time and classifications of the factors and generalize failures and their causes, ii) prediction and prevention and iii) quantification which means the calculation of probabilities for different failure types. The author suggested the use of the Perrow’s Normal Accident Theory which study the complex interactions between automated systems and people, as accidents are always occur in complex, tightly coupled systems, and emergences can happen which these measures are not always adequate. Regarding human reliability assessment, this should contain three parts: a) human error identification (what errors can occur), b) human error quantification (how likely the errors occur) and c) human error reduction (improve human reliability). Although it is not an easy task, it is important to quantify the human error, and Norrozi et al. (2013) highlighted the role of human error in preand post- maintenance and if this neglected, the total amount of estimated risk is likely to be underestimated at least by $68,615.

Noroozi et al. (2013) pointed out that Human Reliability Assessment methodologies have been used in the engineering and transportation. This can be estimated by different techniques such as A Technique for Human Error Analysis (ATHENA) and Cognitive Reliability Error Analysis Method (CREAM). Also, Noroozi et al. (2013) suggested the SLIM which is a probabilistic reliability analysis method and based on an expert judgment where the preference for a set of options is quantified. This method is assess human reliability which derived via human performance influenced by various factors called Performance Influencing Factor (PIF). The basic principle of PIF is that the likelihood of a particular error occurring in a specific situation is influenced by a combined effect of a relatively small set of PIFs (Raafat and Abdouni, 1987 cited in Noroozi et al. 2013). An important issue in SLIM is to determine the weight of PIFs. The most important PIFs in pre- and post- maintenance procedure of equipment are the training, experience, work memory, stress, work environment, physical capability and condition.

Chockalingam et al. (2016) pointed out that safety and security can be integrated and through systematic literature review identified the following 7 related risk assessment methods: i) SAHARA, ii) CHASSIS, iii) FACT Graph, iv) FMVEA, v) Unified Security and Safety Risk Assessment, vi) Extended CFT and vii) EFT. Authors analyse them based on the following criteria: a) citations in the scientific literature, b) steps involved (sequential and non-sequential methods), c) stage(s) of risk assessment process addressed (this typically follows three stages: risk identification, risk analysis and risk evaluation), d) integration methodology (in order to understand which combination of safety and security risk assessment methods are used in the integrated safety and security risk assessment methods), and e) application domain (methods SAHARA, CHASSIS, FMVEA, Extended CFT are used in transportation).

Also, the cost-benefit analysis can be used, although the main disadvantage of this is the transformation of non-economic consequences to monetary values. Thus, the value of security and safety is not adequately taken into account by the approach (Aven, 2008).

The close monitoring of the right operation of all systems is required. According to Leveson (2015) control is achieved by engineered systems, direct management intervention, policies, procedures, shared values, and other aspects of the organizational culture, the called 'safety culture'. Safety considerations are the most important in technical decision making. Also, safety decisions are associated with programmatic considerations, including cost and schedule. These decisions must be based on correct, complete and up-to date information. The core organizational safety values must be documented along with providing the relevant education and buy-in by all employees.

The introduction and the implementation of a safety culture is an important issue for every organization. Maurino (2000) stressed the implementation of a safety culture and define it as "a set of beliefs, norms, attitudes, roles and social and technical practices that are concerned with minimizing exposure of employees, managers, customers and members of the general public to conditions considered to be dangerous or hazardous" (p. 955). Leveson (2015) defines 'safety culture' as the set of values and deep cultural assumptions upon which safety-related actions as taken and decisions are made in the safety control structure. Massaiu (2009) pointed out the establishment of learning organization which should include roles distribution, procedures, interface, training, safety culture, management delegation and this lead to resilience.

The establishment of a specific team consisting by specialists with rich knowledge of the operation and led by an experienced risk assessor for the assessment of each procedure separately is necessary (Aven, 2008; Gould and Lovell, 2009). It is important to make clear how the analyses are to be used in the decision-making process (Aven, 2008). A human factors specialist should lead the assessment team. Operational teams and managers should act collectively monitoring human errors and constantly train, update and improve ways to recognize and recover them (Gould and Lovell, 2009). Maurino (2000) pointed out that decision makers, those who are in top positions must enforce the right communication which includes relevant information on hazards and to potential sources of damage. The author pointed out the importance of management tools, such as monitoring and reporting systems which may uncover the error-inducing factors before produce safety problems having a constant tracking of hazards and evaluation of the risks, as there no sufficient financial resources to completely prevent accidents. Monitoring and reporting systems act proactively, exercise prevention by control, and focus on the process.

Chang and Wang (2010) investigated significant human risk factors among AMTs. In their study, an empirical research of Taiwanese airlines was conducted to determine these risk factors and to show integrating experts' opinions on the relative importance of the risk factors via a quantifiable evaluation approach. A questionnaire was developed for the experts, and the human factors in the SHELL model were modified to categorize the risk factors obtained from the literature and the opinions of senior experts. This study showed that there were nine significant risk factors among 77 preliminary and 46 primary risk factors. Researchers implied that the important risk factors for AMTs analysed and ranked in this way may assist airlines to better focus on their significant weaknesses in terms of management and operation, to improve maintenance operations subject to limited resources.

Kucuk Yılmaz (in press) carried out qualitative risk assessment by considering the factors affecting the aircraft maintenance technician's error obtained from extensive literature review and expert opinions in the field of aviation.

Maintenance organisations should emphasise on the efficient addressing of the risks, as the accidents in aviation sector have significant negative consequences. The use of the appropriate analysis methods, procedures and monitoring and reporting system is required. However, the establishment and the adoption of a safety culture can assist on the right direction.

Risk Assessment Process

Risk assessment, as above mentioned, is a useful process for every organization. Thus, to accomplish their overall goals, enterprises require a risk assessment process that is practical, sustainable, and easy to understand. While enterprise-wide risk management (ERM) is a relatively new discipline, application techniques have been evolving over the last decade. A series of papers published by Committee of Sponsoring Organizations of the Treadway Commission (COSO) aimed at helping organizations move up the maturity curve in their ongoing development of a robust ERM process (Curtis and Carey, 2012). In this study, the risk assessment process, based on the relevant literature and experts opinions, follows four main steps: 1st) determine risk factors, 2nd) identify assessment scales for rating risks, 3rd) assessed each risk factors in terms of impact and likelihood, and 4th) prioritize risk factors by using combined risk matrix.

1st Step: Determine risk factors

In this study, the 12 factors ("dirty dozen") that may lead to errors and accidents in aircraft maintenance are considered the risk factors (see Table 1).

Table 1. *Risk Factors*

Lack of communication	Lack of teamwork	Lack of assertiveness
Complacency	Fatigue	Stress
Lack of knowledge	Lack of resources	Lack of awareness
Distraction	Pressure	Norms

Sources: Dupont, 1997; FAA, n.d.

2nd Step: Identify assessment scales for rating risks

As we mentioned above, traditional risk analysis defines risk as a function of likelihood and consequences (impacts). Indeed, this is an important risk measure (Curtis and Carey, 2012). Impact refers to the extent to which a risk event would affect the company. Impact assessment criteria may include financial, reputational, regulatory, health, safety, security, environmental, employee, customer, and operational issues. Likelihood refers to the probability that a given event will occur. It can be defined likelihood by using qualitative terms as percent or as frequency. Relevant time period should be specified when we are using numerical values as a percentage or frequency (Chaparro, 2013; Curtis and Carey, 2012).The impact and likelihood are classified in a scale of five stages, from 1 to 5, in this study. Table 2 presents impact scale and Table 3 presents likelihood scale. These scales are used for rating the 12 risk factors at Anadolu University Aircraft Maintenance Center.

Table 2. *Impact Scale*

Rating	Descriptor	Definition
5	Extreme	• Financial losses of $X million and more • International long-term negative media coverage; game-changing loss of market share • Significant prosecution and fines, litigation including class actions, incarceration of leadership • Significant injuries or fatalities to employees or third parties, such as customers or vendors • Multiple senior leaders leave
4	Major	• Financial losses of $X million up to $X million • National long-term negative media coverage; significant loss of market share • Report to regulator requiring major project for corrective action • Limited in-patient care required for employees or third parties, such as customers or vendors • Some senior managers leave, high turnover of experienced staff, not perceived as employer of choice
3	Moderate	• Financial losses of $X million up to $X million • National short-term negative media coverage • Report of breach to regulator with immediate correction to be implemented • Out-patient medical treatment required for employees or third parties, such as customers or vendors • Widespread staff morale problems and high turnover
2	Minor	• Financial losses of $X million up to $X million • Local reputational damage • Reportable incident to regulator, no follow up • No or minor injuries to employees or third parties, such as customers or vendors • General staff morale problems and increase in turnover
1	Incidental	• Financial losses up to $X million • Local media attention quickly remedied • Not reportable to regulator • No injuries to employees or third parties, such as customers or vendors • Isolated staff dissatisfaction

Source: Curtis and Carey, 2012

Table 3. *Likelihood Scale*

Rating	Annual Frequency		Probability Descriptor	Definition
	Descriptor	Definition		
5	Frequent	Up to once in 2 years or more	Almost certain	90% or greater chance of occurrence over life of asset
4	Likely	Once in 2 years up to once in 25 years	Likely	65% up to 90% chance of occurrence over life of asset
3	Possible	Once in 25 years up to once in 50 years	Possible	35% up to 65% chance of occurrence over life of asset
2	Unlikely	Once in 50 years up to once in 100 years	Unlikely	10% up to 35% chance of occurrence over life of asset
1	Rare	Once in 100 years or less	Rare	<10% chance of occurrence over life of asset or project

Source: Curtis and Carey, 2012

3rd Step: Assessed Each Risk Factors In Terms of Impact and Likelihood

In this step each risk factor is assessed in terms of likelihood and impact using ratings shown in Table 2 and Table 3 based on the experts' opinions. So all risks are ranked according to two criteria such as impact rating multiplied by likelihood rating. In this study each of the 12 risk factors assessed by likelihood and impact and risk value obtained by multiplying impact and likelihood scale (see Table 4).

Table 4. *Risk Assessment of Factors*

Risk ID	Risk Factors ("dirty dozen" factors)	Likelihood Scale (L)	Impact Scale (I)	Risk= Lx I
1	Lack of communication	5	3	15
2	Complacency	3	3	9
3	Lack of knowledge	5	3	15
4	Distraction	4	3	12
5	Lack of teamwork	5	3	15
6	Lack of assertiveness	4	2	8
7	Fatigue	3	2	6
8	Stress	3	2	6
9	Lack of resources	2	2	4
10	Lack of awareness	5	3	15
11	Pressure	3	2	6
12	Norms	2	2	4

4th Step: Prioritize Risk Factors by Using Combined Risk Matrix

A risk matrix, relating the two dimensions likelihood and impact, is a graphical representation of different risks in a comparative way. After giving a score for 'likelihood' and 'impact', the two dimensions are multiplied to give a numerical assessment of risk factor. Each risk (12 risk factor) is then entered in the appropriate box, called risk matrix, used in this study (see Table 5). The most common way to prioritize risks is by designating a risk level for each area of the graph such as very high, high, medium, or low, where the higher the combined impact and likelihood ratings then the higher the overall risk level (Curtis and Carey, 2012). For example, a risk having an impact rating of moderate and likelihood rating of likely has an assigned risk level of ‘high’, whereas a risk having an impact rating of extreme and a likelihood rating of possible has an assigned risk level of ‘very high’. Risk level descriptions used in this study are shown in Table 6. The results for Anadolu University’s AMO are given in Table 7 when the 12 risk factors, determined in the study, are placed in the risk matrix (including risk id) according to the impact and likelihood values given in Table 4.

Table 5. *Risk Matrix*

	IMPACT				
LIKELIHOOD	INCIDENTAL (1)	MINOR (2)	MODERATE (3)	MAJOR (4)	EXTREME (5)
FREQUENT (5)	Medium (5)	High (10)	Very High (15)	Very High (20)	Very High (25)
LIKELY (4)	Low (4)	High (8)	High (12)	Very High (16)	Very High (20)
POSSIBLE (3)	Low (3)	Medium (6)	Medium (9)	High (12)	Very High (15)
UNLIKELY (2)	Low (2)	Low (4)	Medium (6)	Medium (8)	High (10)
RARE (1)	Low (1)	Low (1)	Low (3)	Medium (4)	High (5)

Source: Victorian Managed Insurance Authority (VMIA) n.d.

Table 6. *Risk Level Description*

Risk Level	Description
Very High	Requires ongoing executive level oversight. The level of risk warrants that all possible mitigation measures be analyzed in order to bring about a reduction in exposure.
High	Action plans and resources required. The level of risk is likely to endanger capability and should be reduced through mitigation strategies where possible.
Medium	This level of risk should not automatically be accepted for risk mitigation but rather a cost-benefit analysis is required to determine if treatment is necessary.
Low	Treatment when resources are available. The risk should be able to be managed via existing controls and normal operating procedures.

Source: Victorian Managed Insurance Authority (VMIA) n.d.

Table 7. *Results for Anadolu University’s AMO according to Risk ID in the Risk Matrix*

	IMPACT				
LIKELIHOOD	INCIDENTAL (1)	MINOR (2)	MODERATE (3)	MAJOR (4)	EXTREME (5)
FREQUENT (5)			RISK ID≠ 1, 5, 10		
LIKELY (4)		RISK ID≠ 6	RISK ID≠ 4		
POSSIBLE (3)		RISK ID≠ 3, 7, 8, 11	RISK ID≠ 2		
UNLIKELY (2)		RISK ID≠ 9, 12			
RARE (1)					

The above table shows that the "dirty dozen" factors have minor and moderate impacts to occur in the Anadolu University's AMO. This shows that the specific AMO efficiently manage these risks and this provides insights for other similar organisations.

Results

Aviation maintenance organisations (AMOs) should focus on human error due to human limitations (physical, physiological, psychological). Aircraft technician error, human error, is an important issue as a minor error may cause a fatal aircraft accident. This study is aimed to determine the factors with very high risk level based on the factors called "dirty dozen", by applying this at an AMO in Anadolu University. These twelve factors, were eventually adopted by the aviation industry as a straight forward means to discuss human error in maintenance (FAA, n.d.). It is aimed to prioritize the risk factors that will cause errors in terms of human factors for an AMO and to take the necessary precautions by the management with a proactive approach. Thus, the maintenance risks can be reduced for an AMO, adopting the suggested by the study approach. In the current study, these factors are assessed for an Anadolu University's AMO, based on the help of risk matrix, taking into account expert opinions, a focus group and a workshop. All assessments from these three sources have been analysed and commented in view of "dirty dozen". According to qualifications of Anadolu University's AMO, there is rare to face lack of resources. Also, the norms has a supportive style in view of corporate culture. Time pressure feels rarely since limited fleet to flight training is served. In addition, AMO of Anadolu University has considerable advantages since there is no corporate based stress or operational fatique. Production planning is established according to minimum stress and fatigue of maintenance personnel. The rest three risks are concern highly individual characteristics as distraction, complacency and assertiveness and Anadolu University face them with extra care. In addition, Anadolu University spends a lot to train its employees and to improve teamwork and sound communication.

Conclusions

It is important for AMOs to improve both corporate performance and minimizing human error, and an effective teamwork should set and this should be aligned with high awareness. When improve level of situational awareness then we may get good results from teamwork and communication related efforts. Aviation requires high level teamwork, clear communication in timely manner. For this reason, the three main risks of human factor assumed to be the communication, teamwork and awareness. When minimizing human factor related errors, this may support effective use of corporate resources, time and all other sources. Every organization may create their own "dirty dozen" and then start to manage these, prioritized risk to manage human factors and to minimise the probability of error.

Anadolu University's AMO has considerable advantages to manage the "dirty dozen", as the study shows. Although, this AMO is not too big, may become a guide and good sample to other maintenance organizations, efficiently managed the "dirty dozen" factors, as all AMOs have common characteristics.

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