PREVENTION OF UNINTENTIONAL HUMAN ERRORS IN AIRCRAFT MAINTENANCE BY INTRODUCING ELECTRONIC COMMUNICATION

Darko Virovac, University of Applied Sciences Velika Gorica, Velika Gorica, Croatia

Irina Kacian, University of Applied Sciences Velika Gorica, Velika Gorica, Croatia

Ivan Ulin, University of Applied Sciences Velika Gorica, Velika Gorica, Croatia

Josip Virovac, University of Applied Sciences Velika Gorica, Velika Gorica, Croatia

Address for correspondence: **Darko Virovac**, darko.virovac@vvg.hr

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Abstract: *According to the law on air traffic, any change in technology or working process in the maintenance organization can lead to the occurrence of unintentional human errors that can threaten the safety of aircraft utilization. The causes of accidents identified as unintentional human error according to the International Civil Aviation Organization (ICAO) annual report are up to 80% of cases. In aircraft maintenance, the biggest factors in human error are communication errors. To reduce the occurrence of human error, according to the prescribed safety system, it is obligatory to find the causes of errors and to define preventive actions to prevent them. To prevent errors in communication, it is necessary to standardize the transmission of information and standardize the form of writing and expression as a preventive measure. A preventive action to prevent errors is to establish communication without writing on paper, establishing communication in accordance with internal procedures and permitted authorizations that must be part of computer communication.*

Keywords: *communications, human factor, accident, safety, corrective action*

INTRODUCTION

The European Union Aviation Safety Agency is the European Commission agency responsible for civil aviation safety in the European Union. The statement presented on the EASA website reads (EASA, 2025):

"There are three main levels of regulatory material in the EASA system:

- *The Basic Regulation itself, adopted by the European Parliament and the Council, binding in all its elements.*
- *The Implementing Rules of the Basic Regulation, adopted by the European Commission; and*
- *Certification Specifications (CS), Acceptable Means of Compliance (AMC) and Guidelines (GM), adopted by the Agency."*

Acceptable Means of Compliance (AMC) are non-binding standards adopted by EASA to illustrate means to establish compliance with the Basic Regulation and its Implementing Rules. EASA requirements for continuing airworthiness, which are regularly updated and incorporate all last changes to the implementing regulations, delegated regulations, acceptable means of compliance and guidance material are set out in Easy Access Rules for Continuing Airworthiness (EASA continuing – airworthiness, 2025).

According to AMC M.A.305(e) Aircraft Continuing Airworthiness Records System defines the aircraft document format used for the continuing airworthiness records system. It should be in the form of information technology or equivalent documents in paper or other form.

The release of an aircraft to service or the release of a maintenance activity according to the EASA FORM-1 form may be carried out using an electronic signature instead of a paper signature. The electronic signature must be executed according to the requirement defined in "AMC Appendix II Part-M - Use of EASA Form 1 for Maintenance" and "AMC M.A.801(f) Aircraft Release to Service Certificate".

The AMC rules define the requirements that aircraft maintenance must implement (organizationally and technically) for electronic documentation and electronic signature. Each organization must adopt its maintenance activity in accordance with the AMC. If the organization applies to the requirements, the competent authority for aircraft will approve it.

At the same time, maintenance organizations must be aware of how to mitigate the risks caused by human factors. Human factor risks are specific to each organization and must be part of the safety and quality system in every organization. The paper presents how the organization mitigated human factor risks when it started with paperless documentation. The main contributions of this paper are as follows:

- To present the initial threats related to human error at the beginning of the implementation of electronic documentation instead of paper documentation.
- How to manage and mitigate human factors at the beginning of the use of paperless documentation.
- This process depends on the awareness of everyone in the maintenance team.

1. FACTORS OF UNINTENTIONAL HUMAN ERRORS IN AVIATION ACCIDENTS AND INCIDENTS

In the case of aircraft accidents or incidents caused by technical failures, the origin of such failures lies in either a technical malfunction resulting from a defect in the design or manufacturing of a component (technical causes), or a maintenance error caused by the human factor (human factor), which refers to unintentional human errors that can occur during the construction or maintenance of the aircraft. Unintentional human errors, or human factor errors, occur due to the physical and psychological limitations of human performance. With the advancement of technology and the adaptation of aircraft design to human characteristics, efforts are being made to enable people to perform work tasks optimally and without operational errors that could affect the safety of air traffic.

In the early days of aircraft construction, technical failures were the absolute cause of aircraft malfunctions. With the development of aircraft construction technology from 1903 to the present day, the ratio of technical malfunctions caused by technical failures versus those caused by the human factor has changed over time, so nowadays technical errors account for a maximum of 20%, while errors due to the human factor have increased to 80% [6]. On the figure 1 is showing statistics of the quantitative relationship of Human Factors and technical failures since 1903 (FAA-H-8083-30B, 2023).

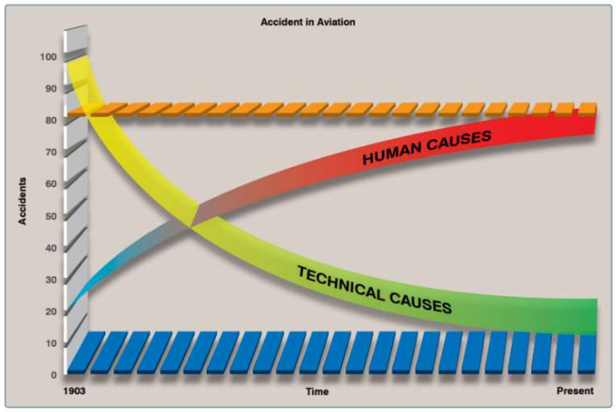

Figure 1 Statistics of the Quantitative Relationship of Human Factors and Technical Failures Since 1903 (FAA-H-8083-30B, 2023).

The numbers of errors occurring during aircraft maintenance account for up to 6% of all errors related to the Human Factor according to the statistical data from the ICAO Human Factor in aircraft maintenance (ICAO-Doc 9824, 2023). Aircraft maintenance organizations are categorized based on the way in which they relate to errors caused by the human factor, as shown in Table 1. With the aim of preventing such errors, aircraft maintenance organizations implement proactive systems to prevent maintenance-related errors.

type of aircraft maintenance organization in relation to implementation the human factors in organization	**the trend of errors noumber due to the human factors and impact to the aircraft safety and maintenance economic**
PATHOLOGICAL- safety is not applicable human factro system is not applied	the number of erros due to human factors are increasing // more than 90% errors are not prevented and maintenance cost is rising//
REACTIVE The organization type that correst the errors causes of human factor causes after errors occurrance. The correction will be corrected after occurance to prevent same type errors in the future	significant numbers of errors are reduced but trend is not acettable //up to 50% errors due to human factors still existed //
PROACTIVE type of the maintenance organization which analyse any one new implementation of technology or organization that can be cause to unatentionaly errors due to human factors. After analyses of causes next step is implementation corrective action for prevention	the errors caused due to human factors are acceptable to the maintenance organization for safety and economic //Up to 90% prevention errors due to possible errors caused by the human factors //

Table 1 The number of errors caused by the human factor in relation to the level of corrective actions in an organization (ESSI, 2009)

As a factor in the aircraft manufacturing process, humans are not perfect and introduce errors into the system. Humans introduce unintentional errors which need to be recognized, and barriers set up to prevent their occurrence during aircraft manufacturing. The goal is to achieve an ideally error-free manufacturing process. Despite all current expertise, errors will always exist, but it is essential to continuously work on preventing them. According to the ICAO statistical data (FAA-H-8083-30B, 2023), there is a noticeable trend of human error reduction in aircraft maintenance when system of proactive maintenance is implemented to mitigate such errors.

To investigate the causes of errors, it is necessary to understand how they occur. The first model applied to an aircraft maintenance organization, incorporating all the factors that define the relationship between humans and their environment as an influence on work performance, was presented by Professor Edwards from Aston University in 1972 (FAA-H-8083-30B, 2023) .The model is shown in Figure 3 and represents individual factors related to a person, as well as those factors which determine the working process. The model is called SHELL (ICAO, Doc 9824, 2003). All the factors are interdependent and have an impact on one another.

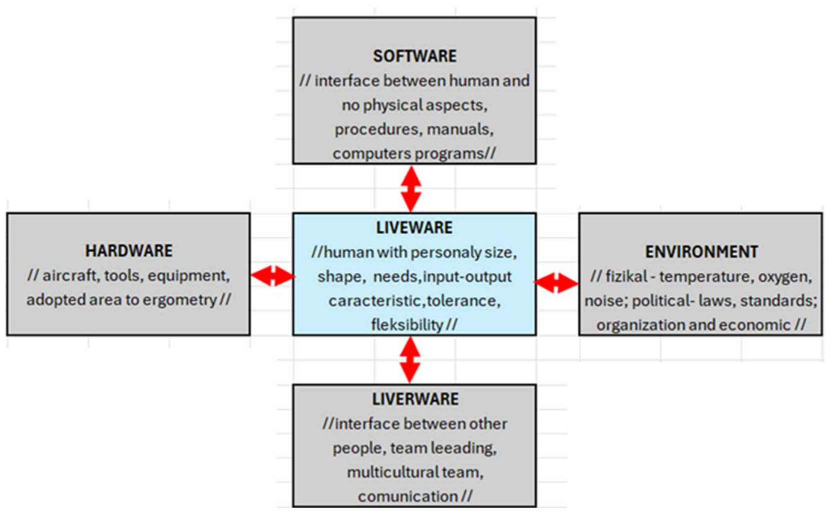

Figure 2 The SHELL Model (FAA-H-8083-30B, 2023)

Individual factors of the SHELL system have the following meaning:

- S (Software) – software includes rules, procedures, and documents that represent the standard operating procedures for work.
- H (Hardware) – machinery and work equipment.

- E (Environment) – the environment consists of the spaces, physiological and psychological conditions in which work is performed and which are beyond the worker's control.
- L (Liveware) – all characteristics of people who perform aircraft maintenance tasks and interaction of individuals with other people, including all other mentioned factors which influence the relationship of a worker with other members of a team or a group.

Gordon Dupout, an employee of Transport Canada, defined the causes of unintentional human errors by classifying them into twelve causes or "The Dirty Dozen" (FAA-H-8083-30B, 2023). Errors are defined based on the research of error causes in the maintenance process. Analysis of how such errors occur represents the foundation for the identification of protective mechanisms or barriers which enable their generation. Figure 4 shows the names of the twelve errors classified under the system known as "The Dirty Dozen."(FAA-H-8083-30B, 2023).

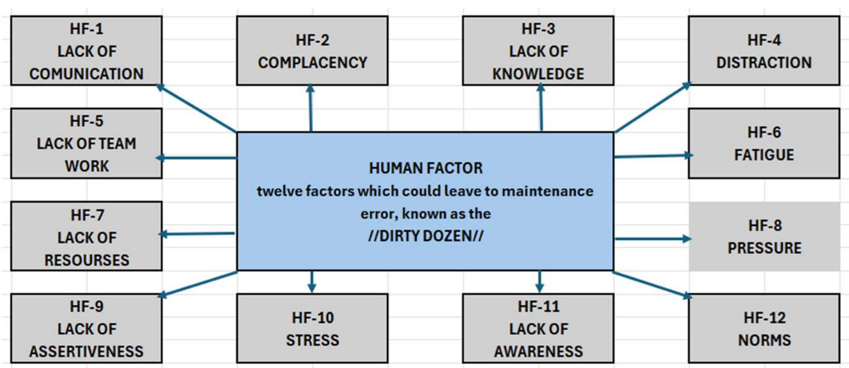

Figure 4 Twelve error factors, known as the "Dirty Dozen"(FAA-H-8083-30B, 2023)

A statistical analysis of errors, according to the annual report of the European Union Aviation Safety Agency (EASA) for 2022 (EASA, Annual Safety Review, 2022), indicates that communication was the third leading cause of errors in that year. The distribution of individual types of errors in incidents and accidents, categorized according to the European Risk Classification Scheme (ERCS) for the year 2022, is shown in Figure 5 (EASA, Annual Safety Review, 2022).

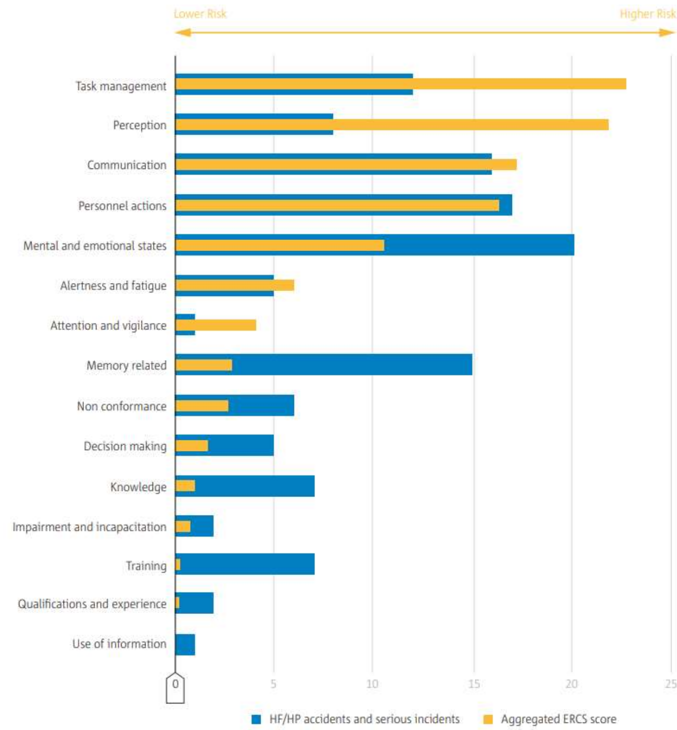

Figure 5 Detailed human factors and human performance event codes by aggregated European Risk Classification Scheme (ERCS) score and numbers of accidents and serious incidents (EASA, Annual Safety Review, 2022)

Below is presented an analysis of occurrence report caused by human factor in an aircraft maintenance organization over a four year period, during which 28 technical errors occurred. The results of the study are shown in Figure 6 (Virovac et al, 2017).

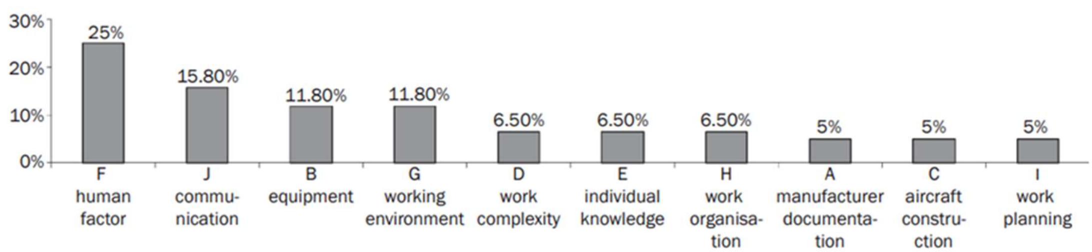

Figure 6 Human Factors errors that contribute to the error occurrence (Virovac et al, 2017)

The analysis included cases of aircraft technical malfunctions that had a direct impact on flight operations. The study focused on aircraft with a maximum takeoff weight exceeding 5700 kg and did not include helicopters. For each incident, an internal incident analysis was performed within aircraft maintenance organizations in which the incident occurred and in accordance with good practice, measures were undertaken to eliminate the factors which contributed to the occurrence of errors. The study involves technical aircraft maintenance in both line maintenance and base maintenance facilities up to the level of annual inspections. The observed time of maintenance operations is 365 days per year, with the maintenance activities being carried out throughout the entire day, including both day and night shifts.

2. COMMUNICATION AS A FORM OF UNINTENTIONAL HUMAN ERROR IN AIRCRAFT MAINTENANCE

According to the annual EASA report for 2022 (Virovac et al, 2017) and the analysis performed in aircraft maintenance organizations, among the top three error causes is communication. By finding the cause of an error, it is possible to determine appropriate corrective tasks whose aim is to prevent future errors. Communication is an active process of transferring information and ideas. The types of communication used in aircraft maintenance are shown in Figure 7.

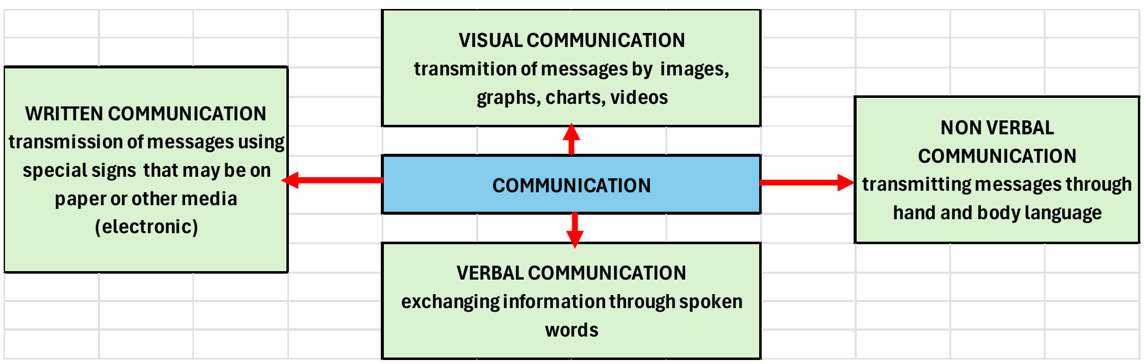

Figure 7 Communication type (created by the author)

Standardization of information transfer in aircraft maintenance refers to the following types of communication:

Visual communication through which aircraft design drawings are transferred is standardized through the complex body sketching system, in accordance with the standards prescribed in the Aviation Maintenance Technician Handbook–General, chapter 4 (Maintenance Technician Handbook – General, 2018; ICAO ANNEX 2, 2005).

Non-verbal communication is prescribed for signs and data transmission through body and hand positions of the person transmitting this information. The signs are unified, so that regardless of the spoken language or cultural status of the persons involved in body language communication, all signs are unambiguous and prescribed in how they are displayed and what they mean. Communication through hand signals is direct communication between the pilot in an aircraft and ground personnel when servicing an aircraft on the ground. Visual ground signals are described in international standard (ANSI, 2024).

Verbal communication is in English and spoken transfer is prescribed by the phraseology which has the exact word form and meaning for the messages conveyed (Maintenance Technician Handbook – General, 2018).

Written communication is determined by legal provisions, according to which written work procedures, work instructions, and work regulations must be structured according to a prescribed template. Descriptions, preventive warnings and the sequence of work in the procedures is structured in such a way as to reflect each working step and serves as an obligatory confirmation of a completed working step in a procedure through a signature. The signature can be handwritten on paper if the procedure utilizes handwritten records or can be a digital signature if the procedure utilizes digital records (Virovac et al, 2017).

Written communication is a form of communication that is unchanged in time and can be sent to several participants who are spatially distant from the source of information and from each other. The organization of written communication represents the creation of maintenance programs, work permits, creation of manuals and maintenance tasks in a written digital form standardized by the aircraft manufacturer. The organization of the internal use of work procedures depends on what has been prescribed by an individual company. Written communication allows permanent records for aircraft maintenance and control of work performance by authorized persons employed in the aircraft maintenance and flight process. The overview of written communication is given in Figure 8.

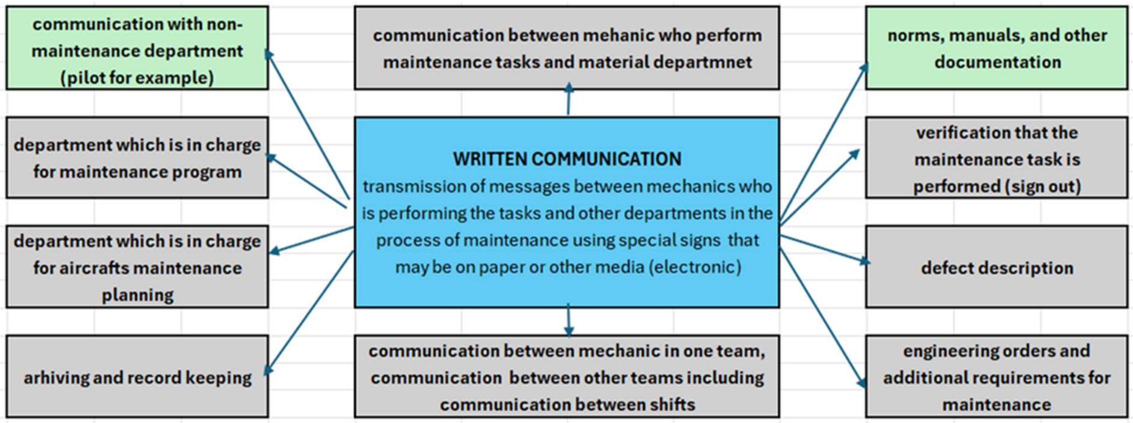

Figure 8 Communication between the staff who are performing tasks and others (created by the author)

The forms of written communication can be the following:

- The paper form of written communication can be exclusively the transfer of messages on paper. A paper-based written communication system limits the timely transfer of data because the data must be physically delivered from the place where it was written to the intended recipient. The numbers of paper-based messages is proportional to the quantity of maintenance tasks so during major inspections it represents a communication problem in data transfer, as inspections may include more than a thousand planned maintenance tasks. Another problem is data storage after the inspection, as spatial and storage conditions are required to keep the written data undamaged during the prescribed data retention period.
- A mixed form of written communication consists of a part on paper and a part in a paperless format. The paper-based part of written communication is primarily used for data exchange within the aircraft maintenance organization. Data related to maintenance manuals and communication with the aircraft manufacturer is part of the communication conducted through digital data transfer via the internet and digitally within the aircraft maintenance organization.
- An exclusively digital communication method, also called paperless communication in English, is the type of communication which does not utilize paper. Rather, internal and external communication within an aircraft maintenance organization is carried out exclusively via computers.

By analyzing communication as a factor contributing to the occurrence of errors within an aircraft maintenance organization, as shown in Figure 9, we can distinguish three communication factors in the communication chain, which have an equal impact on the error occurrence. These are: communication between departments involved in the project, communication between mechanics, and communication between shifts working on the same project (Virovac et al, 2017).

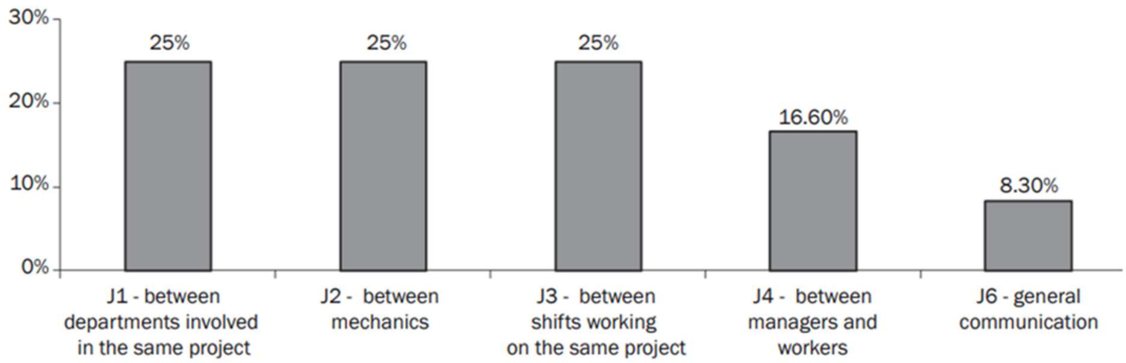

Figure 9 The communication as major factors that contribute to human error (Virovac et al, 2017)

Communication between the mechanics who perform maintenance tasks and reports forwarded to the engineering department responsible for prescribing corrective maintenance tasks after analyzing inspection reports and finding defects, if such corrective maintenance is necessary. The accuracy of the response depends on the clarity of messages sent by those performing maintenance tasks, the speed of information transfer and the ability to implement new maintenance tasks received as feedback from the engineering department or from the parts procurement department. With the purpose of ensuring fast message transfer between the mechanics, task supervisors and engineering, the most efficient transmission in terms of speed is digital message transfer, and the clarity and understanding of the message being transmitted is ensured by standardizing the form of written information.

In the manufacturing process, a quarter of errors consist of the transfer of information from the departing shift to the incoming shift. According to good practice recommendations, the departing shift is obliged to transfer the necessary information for the work to be continued to the incoming shift. The mechanic who is taking over the work tasks needs to check at least three previous steps completed by the previous mechanic in the task documents and sign that he verified the accuracy of completed tasks. The critical link is the departure of the night shift, since it is the moment when the employees leave work tired and noise in the communication channel occurs because they forget to transfer clear and complete messages. To avoid this problem, a standardized form of message transfer is necessary. Educational activities for each individual and training to use operating systems for message transfer.

Message transfer between the mechanics needs to be such to ensure the performance of maintenance tasks, which are organized to prevent communication errors during the performance of those tasks. It is necessary to organize a group of mechanics to work as a team. To implement teamwork, maintenance tasks must be standardized according to the complexity of tasks, rather than the time needed to complete them. All steps in the task are marked according to the complexity of the task and individual step within it, and each employee needs to have an internal complexity authorization which enables them to fulfil individual tasks or steps within those tasks. If the tasks are not standardized according to their complexity, then relationships occur, which are not team relationships, but rather authority-based relationships, and there is a possibility that individual tasks will be completed by a person who lacks expertise to complete them. In such cases, the accuracy of the task performance is jeopardized.

3. CORRECTIVE MEASURES TO REDUCE UNINTENTIONAL HUMAN ERRORS BY INTRODUCING WRITTEN COMMUNICATION THROUGH A COMPUTER INTERFACE

The introduction of paperless communication into the aircraft maintenance system increases the safety of air traffic through the reduction of maintenance errors what has direct impact to arising the profit of an aircraft maintenance organization (CCAA - ASO-2011-005; CCAA - ASO-2010-004). Elements of safety and cost-effectiveness of a digital communication system are the following:

- There are no costs associated with the paper used to write messages and necessary materials and devices used to print and store paper messages. Reduction in the number of copies of the same message on paper since the message is available to everyone who needs this message to perform their work.

- The reduction in the use of paper, printing ink and tools for binding and storing paper records reduces the need for additional energy and pollution-causing materials.
- Reduction in the cost of keeping records, since no special conditions for keeping records are necessary to retain the readability of paper records. Records are kept on servers.
- Increase in the speed of information transfer since it is transmitted directly via a computer, rather than physically by carrying a paper-based message from the place where it was written to the place where it needs to be delivered. At the same time, the amount of work is also reduced.
- Direct remote communication via personal computers, which reduces ambiguities in communication, that is, any ambiguities can be directly resolved or additional answers obtained if they are needed.
- Time needed to purchase materials is reduced since the parts and materials are ordered directly by digital means.
- Data protection since only those people who possess an internal authorization can have access to certain messages.
- The clarity of records is greater since the formats and requirements for printing individual records can be programmed in relation to the format and requirements they need to have.

Introduction of new technological procedures, working tools, expansion of technological powers for work or innovation of any kind represents a direct impact on people's work and attitude towards changes. Each innovation requires safety risk assessment to recognize hazards and assess its impact on safety and cost-effectiveness of work. After the analysis, corrective measures to suppress the hazard should be proposed, actively implemented, their effects and efficiency monitored. If the measure is efficient and it has eliminated the hazard, only the activities are further monitored, while if the hazard has not been eliminated or it has been partially eliminated, the procedure needs to be repeated.

The introduction of digital communication represents an innovation in the technological work process and changes all elements of communication in an aircraft maintenance organization. This requires risk assessment or the identification of threats that could lead to errors in aircraft maintenance, which requires corrective measures to be undertaken to prevent the occurrence of human error due to communication. The standard of the classic work control diagram for preventing the risk of error repetition is shown in Figure 10 (EASA, Annual Safety Review, 2022).

Figure 10 The European Safety Risk Management Process (EASA, Annual Safety Review, 2022)

In order to introduce digital communication into the aircraft maintenance organization system, it is necessary to eliminate the potential causes of unintentional human error which may arise.

The program needs to be acceptable for use and ensure the functionality:

- Introduction of digital communication requires the compatibility of H (hardware) or personal computers with the scope and type of aircraft maintenance tasks. Personal computers need to be of an appropriate size and usability in order to be used during maintenance tasks (at heights, in closed spaces, impact-resistant and chemical-resistant).
- Writing program needs to be compatible with the programs through which the workers receive working procedures and procedures for performing individual tasks.
- Availability of information and communication with the employee who is directly performing the maintenance task, the procurement service and the engineering service need to be such that it allows interactive queries and responses among the users.

The program used for electronic communication must be simple to use and acceptable for every employee:

- For the employees to use the digital communication program, it is mandatory to provide a training course for all employees, where they will be taught how to use computers for work and how to use the program itself.
- During the first time maintenance work is being done on an aircraft, instructors should be provided who could immediately clear any ambiguities if such ambiguities or issues with the program arise.
- After the first maintenance work is completed, analyze any hazards that occurred and provide corrective measures to be undertaken in the future.
- Monitor the efficiency of corrective measures and if additional ambiguities or issues arise, provide new corrective measures.
- Prior to the use and prior to the conducting of the training course, the employee population needs to be analyzed, as well as their attitude towards the use of computers. The content of the training courses for the use of digital communication programs should be based on those analyses. For employees who were assessed as needing more detailed instructions and more practice, additional exercises should be provided, and during the performance of the first maintenance task, the accuracy of writing and receiving messages should be monitored.
- After the completion of the first inspection, it should be verified whether the data were archived in accordance with the prescribed standards.

The introduction of new systems in aircraft maintenance requires adjustments in the organization and management of working teams. All requirements are defined by internal procedures, but any organization is specific regarding working teams. The team leader and any one member is specific person with his own human capability. As the first activity of the introduction of paperless documentation in the working process, a good way to ensure prevent human errors in the work process is to provide support for the organization of the team and support for the individual when performing a particular work task.

4. CONCLUSION

According to the recommendations of aviation regulatory standards, the production, manufacturing, and maintenance of aircraft are based on the principles of ensuring safety and the cost-effectiveness of air traffic. With the aim of preventing unintentional human errors in aircraft maintenance, digital communication should be introduced, whereby the use of paper as the primary communication system is reduced, while this ensures the increase in secure data transfers through the standardization of writing and greater speed of data transfer. Cost-effectiveness is likewise increased through the reduction of costs for writing and the use of paper, as well as the unnecessary physical transport of paper from the information sender to the information recipient. The introduction of electronic communication also reduces environmental pollution, since paper and chemicals used for handwriting are not used. According to the SHELL model, the interaction between humans and IT technology or S (*software*), the people's attitude towards accepting electronic communication is paramount. With the introduction of this innovation in aircraft maintenance through electronic communication, it is necessary to analyze the employee population who perform maintenance tasks to ensure that they accept the use of this innovation at the educational and personal level. The employees should be provided with necessary knowledge to perform their working tasks, as well as necessary support during the acquisition of new technology to prevent issues in the relationship between L (*liveware*) and S (*software*).

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