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DIGITALIZATION IN AIRCRAFT MAINTENANCE PROCESSES

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Abstract. Aircraft maintenance is considered as one of the major expenditures of aircraft operating costs. Notwithstanding that the new aircrafts, engines, and aircraft hard time parts became more durable and maintainable, the maintenance cost is still too high as against other costs like fuel and operational crews. Moreover, aircraft maintenance should be carried out with a high level of safety and security standards. All aircraft maintenance operations are subject to regulations by regulatory authorities. Such authorities can be attributed to European Union Aviation Safety Agency (EASA), Federal Aviation Administration (FAA) and National Civil Aviation Authorities (NAA). The last two decades have become a turning point in the transition from the paper form of the introduction of accounting for aircraft maintenance technical operations into electronic systems, despite all the difficulties associated with these procedures. Such difficulties are not limited to regulatory authorities,-personnel training and investment which is case-sensitive for small companies. Similar to all other sectors of logistics and transportation, digitalization can be one of the key engines of change in aviation, especially in the aviation maintenance; thus, the study of digitalization effects on aircraft maintenance processes at present is an important factor for improving the maintenance processes and reducing the cost of aircraft maintenance. The objective of this research is to define the ability of aircraft maintenance and repair organizations to transform their processes. To that end, a data collection method in the form of a survey was implemented within Maintenance, Repair and Overhaul Organizations (MRO) and among aircraft maintenance engineers. The survey results demonstrate that the aircraft maintenance industry is not yet fully prepared for moving into digitalization in aircraft maintenance processes. However, at the same time, the study indicates the readiness of the personnel involved in the industry to improve themselves and their skills. The industry should invest in the improvement of safety and quality of tasks subject to digitalization by means of development of reliable software/hardware, and provide suitable training for safety and quality personnel.

Keywords: aircraft maintenance, digitalization, maintenance task, maintenance performance, survey, framework.

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Introduction

Over the past decades, digitalization and Artificial Intelligence (AI) have forced their way into almost each and every industry and aviation industry was no exception. However, this interference is still minimal in comparison with other industries. As an example, in 2012 the United State of America invested over $540 billion in information technologies developing advantages in hardware, software, and telecommunication equipment. Another $650 billion invested in business and management redesign to allow the business to take advantage of new technologies. Figure 1 illustrates that in the period between 2012–2023 investments in information technology (hardware, software, and communication equipment) grew (Sava, 2022).

Speaking about digitalization, it was noted that most organizations use digitalization at different levels (Kuusisto, 2015), but there are still many unresolved problems for the aviation industry in this area in general and aircraft maintenance in particular. Aircraft maintenance can be defined as "one or combination of the following activities: overhaul, repair, inspection, replacement, modification or defect rectification of an aircraft or component, with the exception of pre-flight inspection" (European Union, 2014). Simplifying this definition, aircraft maintenance is any activity or process which is carried out on an aircraft or its appliances to maintain it in an airworthy condition allowing the aircraft maintenance engineer to sign the aircraft release to service.

Aircraft maintenance is usually organized by using maintenance checks (blocks) which are packages of maintenance tasks that have to be done on an aircraft after a certain amount of time or usage. Aircraft maintenance tasks can be classified under various categories: in terms of of strategies: Corrective, Pre-determined, Condition-Based and Predictive Maintenance (Duc et al., 2018). In terms of severity, maintenance checks can be classified into base and line maintenance. From the point of view

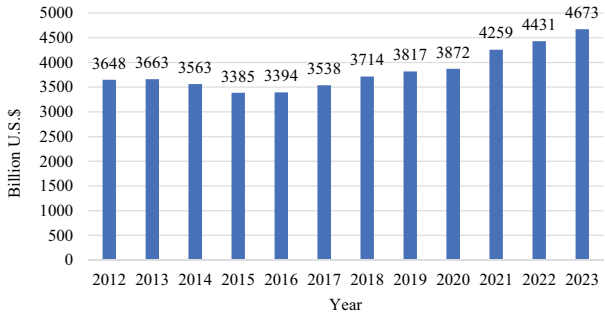

Figure 1. Information technology spending worldwide from 2012 to 2023 (Sava, 2022)

of planning, tasks are classified into Scheduled and Non-scheduled. Scheduled tasks in turn can be classified into Routine and Non-routine tasks.

Note that both line and base maintenance contain routine and non-routine tasks. Routine tasks can be defined as tasks, which follow standard known rules and thus, these tasks can be automated as it was mentioned by Acemoglu and Autor already in (2011) based on rule-based algorithms – for instance, using Internet of Things (IoT) and Artificial Intelligence (AI).

As highlighted in Schmücker et al. (2021), maintenance, repair and overhaul organizations (MRO) have enormous potential to increase efficiency and reduce barriers to accessibility by implementing various digitalization concepts. However, analyzing the aviation industry, it was seen that aircraft maintenance is still experiencing some difficulties in the transition to digitalization, which are associated with the following three main obstacles to digitalization in service: data warehouses, digital readiness and personnel adaptation (Sprehe, 2021).

The purpose of this research is to define the ability of aircraft maintenance and repair organizations to transform their processes. A survey was conducted among MRO and aircraft maintenance engineers to take their opinion and find out their readiness for transitioning to digitalization in maintenance processes.

1. Related works

Maintenance along with ground handling processes consumes the largest part of aviation business direct operation costs. As it is seen in Figure 2, aircraft and its appliances maintenance costs is 23% of direct operational costs for aircraft with the average capacity of 186 seats (International Civil Aviation Organization [ICAO], 2017).

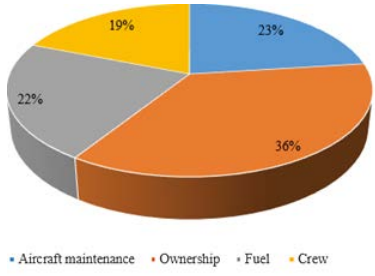

Figure 2. Aircraft operation direct cost breakdown (ICAO, 2017)

Any delay in maintenance will lead to disturbance of flight schedule and, in turn, will cause a flight delay or even flight cancellation. Apart from financial losses, this will have an impact on the air carrier reputation. As an example, in Riga International Airport in 2016 the flight delays caused by planned maintenance were 7%, while the share of unplanned maintenance (aircraft problems and failures) was 52%. The total of flight delays for maintenance was 59%. It was the main reason of flight delays, whilst the second source of delays was ground handling processes with 13% (Alomar et al., 2017).

Effective Management of aircraft technical maintenance processes aims at meeting safety and security standards. MRO during the last decade has started to implement digital technologies to improve the maintenance processes management and solve part of problems facing management and Aircraft Maintenance Licensed Engineers (AML) and to reduce the workload for all the concerned parties (Kivanç et al., 2021). Computing power has increased with time, and the growth of this power is continuing at warp speed with the development of more efficient data processing facilities. This fact opens the door to the use of digital technologies in some case-sensitive issues such as aircraft maintenance (Arntz et al., 2019) and to complete certain tasks assisted by AI, IoT as well as drones (Esposito et al., 2019). Moreover, using computing technologies will help increase the safety and efficiency of maintenance processes.

To date, ample research is focused on Knowledge Management (KM). These investigations demonstrated the positive impact of information technology in this regard (Ratna & Kaur, 2016). However, there are yet little research performed on KM in the aviation industry in general and in aviation maintenance in particular. Lately, a huge amount of information is being generated in aircraft operations and maintenance, which propels the need for alternative technological solutions (Abdallah & Fan, 2020).

In light of these facts, digitalization can play a key role in reducing the downtime period required for maintenance by optimizing the troubleshooting processes using automation and AI. Moreover, the usage of dedicated software for controlling and management of aircraft maintenance, as well as Continuing Airworthiness Management software is applied in maintenance planning and spare parts supply chain management. Airbus in October 2016 launched Airbus's Hangar of the Future project. This project contains numerous technologies for transformation towards digitalization and automation in aviation maintenance processes to improve maintenance processes efficiency. Hangar of Future includes the Internet of Things with RFID technology for identification and track tools and parts; drones and robots – for obtaining information about aircraft structure, flight hours, etc. (Airbus, 2016; Uniting Aviation, 2019).

Within the framework of Singapore Air Show 2020, the Singapore Aerospace Association hosted the Singapore Aerospace Technology Leadership Forum. The Forum was designed to deal with two areas of the emerging technology the increased use of AI and digitalization in aerospace industry. One more objective was to clarify how the new technology and aircraft designs could tackle the challenge of climate change. Digitalization should be used in conjunction with physical systems – not only as a record of what has been done. The conclusion from the forum was "To progress between needs and solutions, we need both physical systems and digital system models" (Read, 2020).

AAR Corporation starts adopting some technologies such as augmented and virtual reality as well as drone technology for visual inspection performance during heavy maintenance checks completion. Drones perform a scan of aircraft fuselage in about 30–60 minutes which usually takes up to 24 manhours using traditional inspection method. Using these technologies allow technicians to identify malfunctions and create a digital record of the condition of the aircraft faster than using the technicians eye (Bellamy, 2022).

The digitalization impact on labor is one of the most critical points while moving forward to more advanced technologies. Many researchers studied and examined the impact of digitalization on various sectors of aviation business performance and aviation employee productivity. Less studies were dedicated to the research of the aviation tasks performance and employee autonomy (Cijan et al., 2019). The employment level in aviation industry will be reduced, however, the advanced technologies-based production requires a higher level of employment. Thus, the general level of employment could be at an acceptable level of balance.

European Company Survey (ECS) could not find any cause and effect relationship between digitalization and staff number change while proceeding the survey within 3 years (Eurofound, 2021). The transition rate from paper to digital-based processing system in aviation maintenance organization is still below expectations despite the fact that many organizations invested a lot in this field. Not all organizations are able to perform this transition for many reasons. The age of some employees does not allow them to be able to follow the digitalization processes. Understanding of technologies and IT is not an easy issue for aviation technicians who are 50+ years old. Moreover, the management of organizations and Civil Aviation Authorities in many countries still believe in Digitalization sincerely. Apart from European Union Aviation Safety Agency (EASA), Federal Aviation Administration (FAA) and National Civil Aviation Authorities (NAA) demand that all aircraft documentation should be confidential and should be stored in secured and protected environment with restricted access.

In fact, one of the major problems faced in MROs variable and unpredictable processes in the aerospace maintenance industry is to maintain a high level of alignment between process data available in operators' information systems and the current state of the process in the MRO. The misalignment occurred mainly due to the hardly automatable nature of this filed of industrial process. MRO performs the ongoing updating of aircraft status advance in MRO process, recording the operations into the operator systems. Thus, proper information and communication system is quite important to overcome this misalignment (Esposito et al., 2019).

Thus, moving to digital forms should be subject to cybersecurity and 100% protection of this data from unauthorized access (WeTransform, 2022; Toves, 2015). In light of digitalization, the productive solutions within MRO should take into consideration the creation of a network of trusted suppliers of technologies, which corresponds to the aviation maintenance requirements and is within regulatory framework expectation.

As per the research conducted by Latorella and Prabhu, it was stated that human errors have the most severe impact on accident curves and losses of lives, flight delays and obstruction of both productivity of equipment and operation (Latorella & Prabhu, 2000). Thus, transformation to digitalization could positively affect these factors by reducing the consequences from human errors and their number and severity.

On February 15, 2022 in Singapore, Asia Digital Engineering, the engineering arm of Capital A, had signed an agreement to build integrated MRO facilities based on know-how technologies. It was expected to occupy the area of 380,000 sqft on the territory of Kuala Lumpur International Airport (KLIA). At maturity, the new state-of-the-art facilities will be able to provide heavy MRO services for up to 14 commercial aircraft at any time (Malaysia Airports, 2022). The workflow of maintenance processes should be kept smooth and safe, taking into account the complexity of aircraft maintenance processes and multiple actors playing role in this industry (Bergkvist & Sabbagh, 2021).

2. Research methodology

In this research the inductive approach was used and from this approach it is expected that the obtained data from the surveys generate knowledge and understanding of the real situation, and, based on that, theory can be generated.

A survey was conducted to define how digitalization affects the performance of aircraft maintenance. The survey was performed using Google Forms. The survey was distributed between MROs and aircraft maintenance engineers through Authors LinkedIn network and via e-mail. Questionnaire was sent to various EU countries, USA, North Africa, Nigeria, Middle East, Gulf States and Honk-Hong. Non-probability sampling method was used as it is allows non-random selection based on convenience. This method allows the author to choose certain criteria of the approached respondents, consequently, allowing easy collection of data. All individual questionnaire responses are kept strictly confidential to the research team. The survey form was accessible from August 1st till August 15, 2022.

The Questionnaire included few parts and 13 questions:

- the first part included traditional questions about general characteristics of respondents: occupation and age;
- the next part consisted of two questions which were devoted to identifying the tasks of aircraft maintenance processes that can be automated;
- the third part also consisted of two questions, where the authors liked to define the specific work environment where tasks could be automized and the effect of digitalization on maintenance engineers' performance;
- the next three questions were designed to verify the relation between maintenance engineers' performance, the quality and safety of performed tasks and digitalization;
- the next question was designed to identify the ability of maintenance staff to develop themselves;
- and the last 2 questions were designed to evaluate the level of trust of the tasks performed using digitalization processes, and which obstacles could affect the successful adaption of digitalization into aircraft maid attendance.

Most of the questions are referred to as multiple-choice questions – they require to choose the answer. They allow facilitating the analysis of results. The analysis is focused on understanding the level of readiness of respondents to digital transformation. Moreover, the purpose is to identify the existing problems, challenges and opportunities.

3. Findings

During the period specified (from August 1st till August 15, 2022) 95 respondents answered to the questions.

The first questions were designated to identify the occupation and age group of the respondents. 42% of the respondents were aircraft licensed maintenance engineers, 35% belonged to the management group in aircraft maintenance and Continuing airworthiness such as Managers in Part-145 organizations MROs and Continuing Airworthiness Management Organizations (CAMO), and 23% belonged to engineering personnel in CAMO, see Figure 3.

46% of respondents belong to the age group 25–40; the second largest group was respondents of age 51 and more than 29%, the last age group 41–50 was 25%.

The reason for making the group intervals unequal is that the aircraft maintenance engineers can obtain their license when they reach the age of 21 as a minimum, so they need at least some time to gain experience and be able to respond to the questionnaire. Thus, the decision to start with the age of 25 was made. The age of 60 primarily was the age limit for this questionnaire as usually aircraft maintenance engineers retire at this age. The authors decided to divide the respondents into three groups. The first one consisted of engineers who are 25–40 years old as their age group is considered more advanced and familiar with new technologies approximately at the same level. The remaining 20 years were divided into two groups: 41–50 and 51+.

The next questions were designated to identify the tasks of aircraft maintenance processes that can be automated. The first one was about the nature of tasks – routine/non-routine, while the second question was about the type of tasks –physical/paperwork. 66% of respondents stated that only routine tasks can be automated, however, 28% declared that both routine and non-routine tasks can be automated (see Figure 4a). 56% of respondents conceded that only paperwork tasks are subject to automation and 35% think that both paperwork and physical tasks can be automated (see Figure 4b).

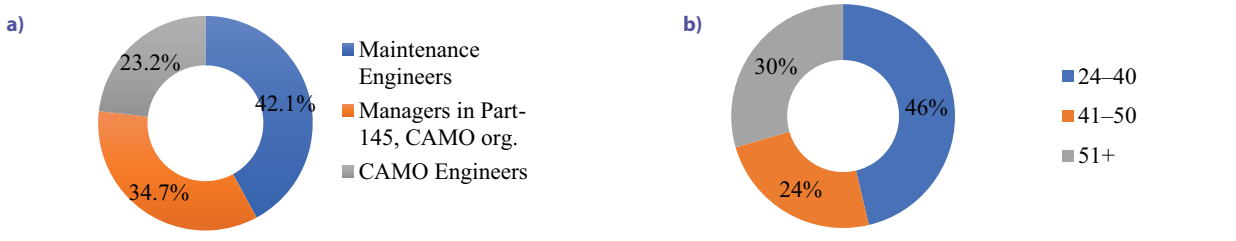

Figure 3. Distribution of respondents by age groups (a) and occupation held (b)

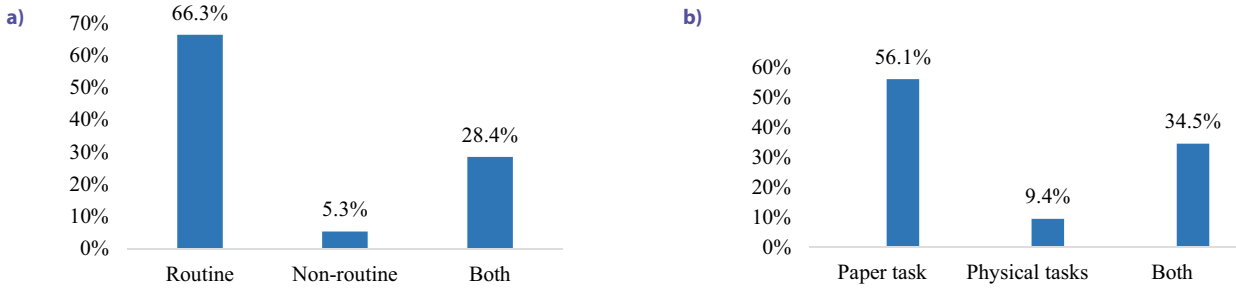

Figure 4. Distribution of tasks which can be automated: classification by task nature (a), classification by task type (b)

The next question was designated to clarify the opinion about the environment which is most suitable for maintenance tasks automation – hangar (Base) or line maintenance. 53% declared that only Base maintenance tasks could be automated, yet, only 44% declared that both base and line maintenance tasks cold be automated, see Figure 5.

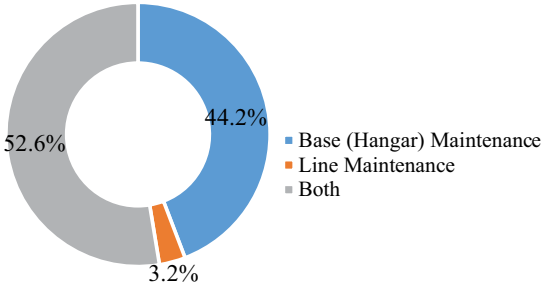

Figure 5. Distribution of tasks which may automated, categorized by environmental conditions

The following group of three questions were devoted to the respondents' opinion on the relation between maintenance engineers' performance, the quality and safety of performed tasks and digitalization. 77.9% of responses stated that digitalization will affect the performance of aircraft maintenance engineers (see Figure 6). 78% of responses claimed that digitalization will affect/strongly affect the quality of aircraft maintenance (see Figure 7). Moreover, 72% of responses confirm that the safety level of aircraft maintenance will be affected/strongly affected by digitalization.

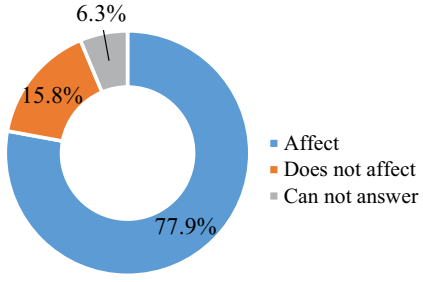

Figure 6. Effect of digitalization on license maintenance engineer performance

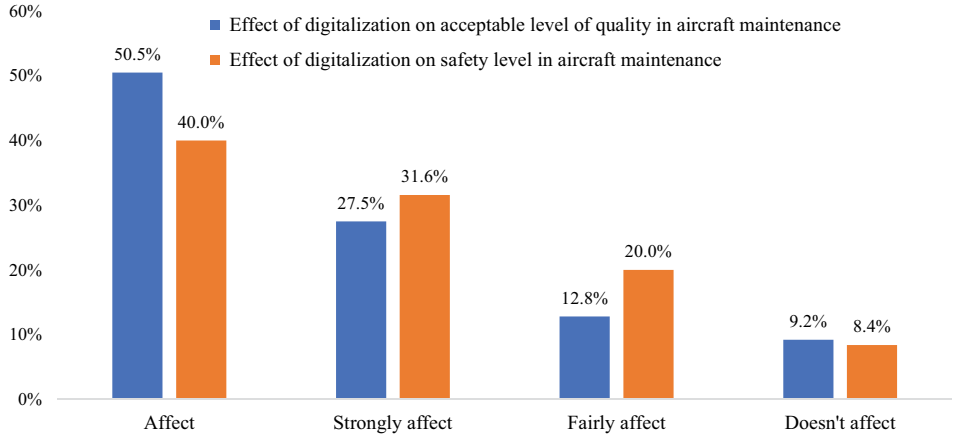

Figure 7. Effect of digitalization on quality and safety level in aircraft maintenance

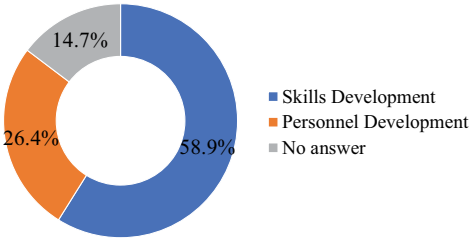

Figure 8. Ability of personnel to improve themself

The next question was designed to discover the ability of personnel to improve their skills to follow up with changes, which may accrue in aircraft maintenance industry as a result of the introduction of new technologies. 59% of responses were ready, and the respondents liked the idea to improve the development of their skills, while 26% liked the idea of improving their personal development (see Figure 8). This indicator is quite important as it can be felt that the personnel involved in aircraft maintenance industry are looking to improve themselves. This can be achieved by a scrupulous, persistent, and continuous training, including, in particular, gaining the knowledge about innovations in digitalization experience gained by other companies worldwide. The stakeholders should guide the personnel in a correct way, improving their skills and knowledge to ensure the introduction of new technologies into aircraft maintenance processes such as IoT and AI.

The following question was designed to clarify the level of trust in tasks performed by robots (drones, AI, etc.). Figure 9 demonstrates the responses feedback and Figure 10 illustrates the spreadsheet of trust level split up by age groups.

Responses were requested to rate the level of trust on a 1–10 scale. The reason for using 1–10 scales for this issue is that maintenance engineers are more technical-minded as against those pursuing science. Thus, for engineers and technicians this scale is more familiar and more understandable. On the one hand, the result of the answer to this question requires a very close attention as the results

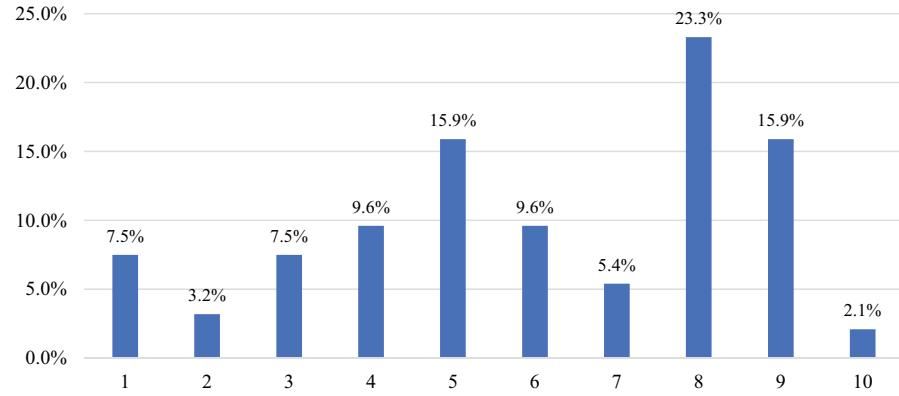

Figure 9. Responses trust level of the tasks performed by robot (from '1' – very weak to '10' – strong trust)

varied from "very weak" trust to "strong" trust. For a better understanding of the results of this question, the authors decided to split the responses into two main groups. The first group included the responses which rated the trust level from very week to average (from 1 to 5); the second group is the responses which rate the trust level from above average to strong trust (from 6 to 10). 43% of respondents think that they have weak trust in the result of such performance, and they rate this performance from 1 to 5 points out of 10. 57% of responses gave 6 to 10 points out of 10. Such a strange response required more detailed studying and investigation. If going deeply into this question and check all the responses feedback one by one as distributed by age, figures were obtained that are more precise. 24 responses (85%) from the age group 51 and higher plus 12 responses (52%) of age group 41–50 rate such kind of performance as very weak to weak, and only 5 responses (9%) from age group 25–40 rate this performance as weak. 39 responses (91%) from age group 25–40 rate this performance as trust to strong trust. On the other hand, this distribution demonstrates that a large part of maintenance technicians does not understand the meaning and the real benefits of digitalization of maintenance processes. This force stakeholders to think seriously about training of personnel to match their knowledge with digitalization subject.

Such separation in opinion by age demonstrates that old generation of aircraft maintenance personnel either is not able to follow up with technologies or they feel inherent danger of changing their habits. Moreover, from the point of view of human psychology, it is difficult to change the mentality of thinking after the age of 40–50; older people face difficulties when adapting to any change (Matamales et al., 2016), thus, the industry should concentrate on younger personnel to get them involved in the process.

The second-to-last question was designated to identify the obstacles that can affect successful adoption of technologies into aircraft maintenance industry. This question was an open question type – no options were provided to responders. All the respondents gave their opinion in the form of a short essay. Analyzing the feedback from 95 respondents, the author classified their responses into ten main categories (see Figure 11).

The above distribution illustrates that the main obstacles are: high cost and huge investment, lack of sufficient training, software/hardware errors and poor reliability, regulatory and management-related issues. These four obstacles constitute 51.5% of the total number of responses. This confirms the necessity of huge investment as stated above. Some investments are required for training, software/hardware development and improvement. Moreover,

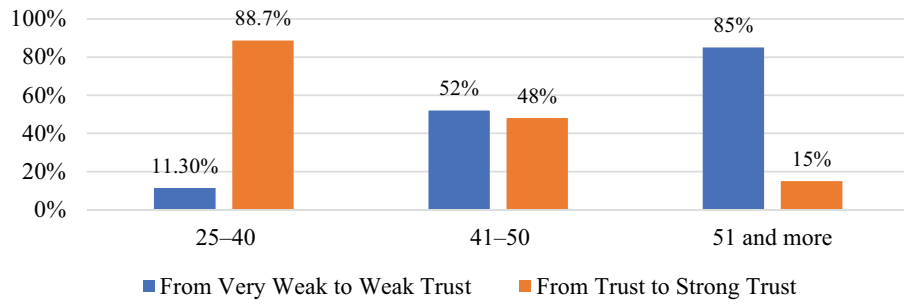

Figure 10. Responses trust level spreadsheet by age group

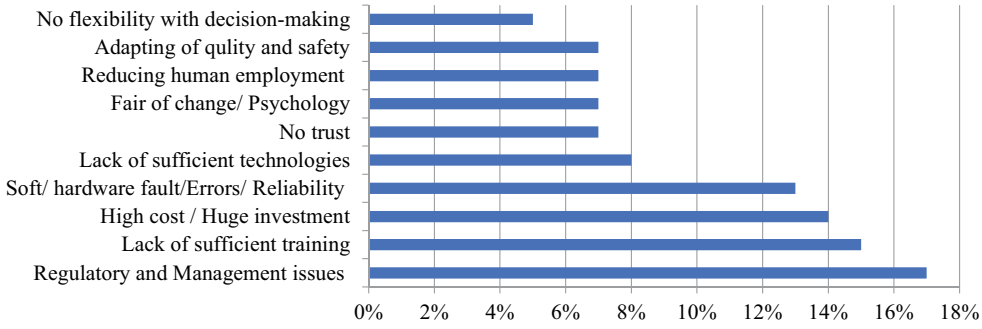

Figure 11. Obstacles which affect successful adaption of technologies into aircraft maintenance

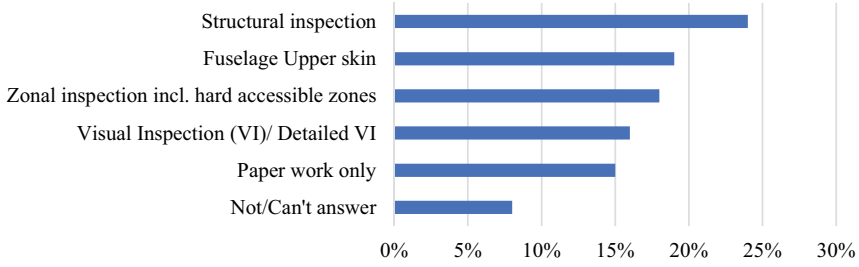

Figure 12. Aircraft zones/tasks which may be inspected using automation

improvement of management and regulatory thinking is required in order to progress and implement innovations into aircraft maintenance industry.

The last question was set to clarify which tasks/aircraft zones, in the opinion of the industry, may be inspected using automation. Same as the previous question, the last one was also of an open type – no options were provided to respondents. All the respondents gave their opinion in the form of short answers. Analyzing the 95 responses feedback, the author classified the responses into six main categories, see Figure 12.

4. Discussion and digital transformation framework

The survey findings illustrate that the aircraft maintenance industry is still not fully ready for moving into digitalization in aircraft maintenance processes.

However, at the same time, the study demonstrates the readiness of the personnel involved in the industry to improve themselves and their skills. To that end, the industry needs to invest heavily into training employees and managers involved. On the other hand, special attention should be paid to regulatory issues. Without adequate regulation, the digitalization in aircraft maintenance will face difficulties in implementation.

Results demonstrated the huge fear of any change towards digitalization. Aircraft maintenance cannot accept such a reduction of safety and quality level, furthermore, the maintenance engineer's performance should be improved with time, but never deteriorate. The responses to these three ultimately important questions make us think about how to keep the safety and quality level and maintain the performance of engineers within the accepted limits. To do that, the industry has to invest more and more to train the personnel involved and invest more in all aspects related to digitalization in aircraft maintenance – such as software/hardware, verifying and identifying the hidden pitfalls of digitalization process. From the Author's perspective, specialized training for compliance with monitoring personnel should be developed along with modern checklists, which correspond to the digitalization processes.

The industry should invest into improvement of safety and quality of tasks subject to digitalization by means of development of reliable software/hardware, providing suitable training for safety and quality personnel.

In Table 1 the authors present their vision for digital transformation framework and it is the blueprint of how a company moves through a period of significant changes and guides all levels of the company. So, any company should first of all understand why they need digitalization.

Any digital transformation framework is only a tool that will assist with the change, but it also needs to be suited for whatever the company encounters. To enable any digital transformation framework to operate, the top management of the company needs to have the right mindset to adapt and adjust as the transformation unfolds.

Table 1. Digital transformation framework

	Digitalization in aircraft maintenance industry				
Why	Optimizing maintenance costs		Minimizing human errors		Reducing the downtime devoted to maintenance processes
What	Paper-work tasks		Physical tasks	Routine tasks	Non-routine tasks
How	Means for transformation to digitalization				
	Develop digital culture at all levels; Regulatory authorities, Management and personnel involved in aircraft maintenance industry	Formulate: 1. List of digital goals 2. Means and infrastructure required for this purpose 3. Formulate considerations about the target group of aviation professionals who are most suitable for this transformation 4. List of required training for all parties involved in this process	Implementation of training related to digitalization and helping employees to achieve required level of skills development	Determine and create roadmap for transformation to digitalization	Stakeholders are required to allocate visible funds for: 1. Development of new digital software and hardware required for transformation to digitalization 2. Training for authorities, management staff and engineers involved in the industry 3. Maintain the acceptable level of safety and quality in aviation maintenance 4. Maintain high level of cyber security as all aircraft maintenance records are considered as highly confidential

Conclusions

Digitalization enables more efficient processes in aviation maintenance: increased performance and decreased the human errors. Innovations like IoT, AI, cloud computing, robotics, additive production processes etc., allow new ways to communicate and new intellectual approaches as well as new business models. Digitalization is shaping a new generation of engineers and managers.

Knowledge Management research in aviation industry should be in place which leads the management staff to correct thinking about importance of digitalization in aviation maintenance. All stakeholders in the aviation maintenance industry should have a clear vision on how to move toward digitalization. An adequate roadmap should be set up in order to reserve the required investment which will be needed for this transformation.

Through the answers of the questionnaire, it was confirmed what it was mentioned in the related works review; the aviation sector is very complex and regulated and not very easy to facilitate the introduction of digital solutions. The results confirmed the heterogeneous opinions about it and strongly depended on the age of staff. Through training, employees were able to stay up to date with new computer programs or new systems implemented to improve their job performance. Moreover, despite the average age of the workforce being high, training and motivation may made workers less reluctant to changes. As the results from Survey illustrated that not all personnel interested in digitalization, thus, stakeholders shall think about real investment required to motivate the personnel to participate in training courses required for transformation. The survey shows that there are differences in staff point of view over digitalization transformation. Thus, stakeholders have to think about to whom and how they have to provide training. Serious discussion should be set up with personnel with age 50+ to explain the needed and importance of transformation.

Transferring to digitalization in aircraft maintenance will be easier to achieve with new generation of employees and more progressive managers. Stakeholders shall manage and direct the employees to the right way in improving themselves to cope with digitalization processes, and for this purpose, stakeholders should invest valuable resources.

In order to develop new up-to-date regulations which, correspond to revolutionary transformation to digitalization, tight cooperation between the industry and regulatory authorities should be in place. While transforming to digitalization in aircraft maintenance industry, stakeholders should pay attention to the quality and safety of maintenance performance. The quality and safety should be maintained at an acceptable level as designed by regulatory frameworks.

Acknowledgements

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