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Evaluating the Impact of Maintenance Personnel Competencies on Aircraft Safety and Maintenance Efficiency

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Abstract. *Aircraft maintenance is highly regulated field where safety and efficiency are paramount. Taking in account that maintenance and ground handling accounting for approximately 23% of direct operational costs and to remain competitive, airlines prioritize performance-driven maintenance management. In other hand, as the technicians are important pillar of the system, this paper examines the correlation between the quality of maintenance technicians—and maintenance performance, considering factors such as compliance with safety standards, timely responses, and cost efficiency. The analysis draws on a survey of 90 respondents within key maintenance roles, assessing technician experience, morale, skills, stress, communication, and adherence to safety protocols. Through canonical correlation analysis, results suggest that communication, experience and morale have a statistically significant effect on maintenance effectiveness; whereas stress or safety perception do not affect performance noticeably. The study contributes to literature by highlighting the role of technical and non-technical skills in optimizing maintenance operations. However, further research with expanded sample sizes is needed to solidify these findings and refine best practices for workforce development in aeronautical maintenance.*

Keywords: *aircraft maintenance, human factor, safety, engineer's skills, performance measurement.*

I. Introduction

Aircraft maintenance activities and engineering have a highly regulated and dynamic environment, with interdependent and complex systems and technologies, thorough and formalized task procedures and documentation (McDonald et al., 2000). In addition, Aircraft Maintenance along with ground handling processes consumes the largest part of aviation business direct operation costs : 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, 2017).

It is no exaggeration to say that the field of aviation maintenance is comparable to surgical interventions on the human body: human error is not tolerated and optimal performance is always demanded in this sector. Maintenance technicians must meet very high demands (Ward et al., 2010). This becomes all the more crucial due to the strong correlation between accidents and maintenance errors (Fogarty, 2004).

Aircraft maintenance is also a field characterized by a high workload. In fact, according to (Wyman, 2022) the possibility of an aviation mechanics' shortage has been discussed for years, the industry in faced the issue in 2023. All this explains the growing interest in a performance-based management culture for aeronautical maintenance entities (Fogarty, 2004). Thus, the stakes are high and only the achievement of high levels of performance is likely to respond to the challenges of this sector of activity (Hobbs, 2008).

Indeed, aeronautical maintenance is a key area which is beginning to be strategic for airlines. For these, the cost of planes grounded for maintenance reasons is very high and in a context of fierce competition, this will have direct consequences on the competitiveness of the company. In fact, the aeronautical maintenance function, whether it is an internal or external function (external maintenance service), must be up to the required performance.

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Moreover (Rouse et al., 2002) considered that: "maintenance services must be capable of responding to all planned maintenance demands as well as intermittent emergencies, requiring effective integrated planning and control systems to ensure continued commitment to functional balance, responsiveness and operational improvement.".

In this context, the performance of aeronautical maintenance is measured by the capacity of maintenance entities to respond to planned and urgent requests from airlines while respecting safety standards, national and international standards, as well as specifications, and preserving internal balances. According to the International Civil Aviation Organization, the performance of maintenance functions is assessed by the percentage of non-compliance or deficiency with the stipulated minimum requirements.

Indeed, the performance of aeronautical maintenance is based first on efficiency, that is to say the carrying out of maintenance missions in accordance with the national and international standards and requirements of the sector, then on the search for efficiency, which corresponds to the accomplishment of these missions with minimal cost, both financially and organizationally (Mofokeng et al., 2020). Other visions or definition approaches have retained a triple objective to address aeronautical maintenance performance: zero defects, zero breakdowns and zero accidents. (Agustiady & Cudney, 2018). In other words, the challenge was to improve efficiency (processes and costs) as well as customer satisfaction, while ensuring quality and safety (Ward et al., 2010).

Thus, it seems that maintenance technicians play a very determining role in the performance levels achieved. According to (Hobbs, 2008), citing the International Air Transport Association report, improper maintenance was a factor in 17% of airline accidents in the period 2014–18. This means that the productivity and quality of human resources influence the performance of aviation maintenance organizations. In other words, the construction of maintenance systems free from failures is dependent on the quality and performance of human capital (Amalberti, 2001).

This work falls within this framework. Indeed, this article aims to study the relationship between the performance of aeronautical maintenance, as defined previously, and the performance or quality of maintenance agents, in particular aeronautical maintenance engineers.

Moreover, international law determines the quality of aircraft maintenance processes by setting requirements concerning, among others quality management system, safety management system and operator's competence (Stadnicka et al., 2017).

Nowadays, with the increased level of technology development, nations around the world are trying to enhance competitiveness by developing manpower skills. The promotion of job performance is becoming the main focus of many organizations seeking to achieve a long-term strategic advantage. To fulfill this requirement, organizations must carefully manage their employees' competencies and function with the best possible outcome (Dawood, 2022).

When describing human resources, (Fazel-Zarandi & Fox, 2013) identify skill as the core element that is crucial for performing certain activities in the workplace. Furthermore, they consider expertise and competency as revealing the level of performance of the associated activities.

More specifically, they specify skills as what enable the performance of activities, and relate proficiency in a skill to the span of activities that one can perform in addition to measurable attributes related to that skill (Stahl, 2014).

According to the European Aviation Safety Agency (EASA), aircraft maintenance is defined as "any operation or combination of overhaul, repair, inspection, replacement, modification or correction operations defects on an aircraft or its components, with the exception of pre-flight inspection" (Alomar & Yatskiv, 2023). This is an area that requires setting up qualified and adequate maintenance infrastructures, recruiting highly competent and experienced staff and regulatory requirements. All this is part of a collective performance approach. Maintaining the airline fleet at a consistently high level of safe and efficient operation is a crucial advantage (Rouse et al., 2002).

Although the degree of organization, control and monitoring systems, as well as internal infrastructure and automation are important in aeronautical maintenance operations, human capital alone remains an essential and determining element (Shanmugam & Robert, 2015).

In this sense, it was quickly noted that there is a consensus in the literature on the central role of human capital in the effectiveness of aeronautical maintenance missions. But, it reveals different approaches in examining the linkage between Aircraft maintenance and technicians skills.

The complexity of aircraft maintenance operations require specific skills and pose a number of organizational and technical requirements to be respected (Stadnicka et al., 2017). As such, the effectiveness of tasks performed by the directorate of aeronautical engineering directly impacts flight safety, which in turn influences the organization either positively or negatively. Therefore, improving employees' competencies will improve individual performance, have a positive impact on the safety of flight operations and enhance the overall performance of the organization (Dawood, 2022).

For military aircraft such F-16 jet fighter, by using simulated aircraft maintenance trainers, (McConnell, 1984) analyzed individual skill training at the installation level and determined the linkage between this training and maintenance productivity and emphasized the importance of structured training programs in improving maintenance outcomes for the F-16 aircraft, contributing to better performance and efficiency in the Air Force.

In the opposite, skill based error and mistakes form a significant part of the effect of aviation human factors as far as maintenance is concerned. Many air and ground incidents have been traced back to have occurred due to lapses that occurred during handling and maintenance of aircraft, which resulted in such human errors (Kharoufah et al., 2018).

Proper identification of the possibility of such mistakes and errors to occur in a given maintenance environment and finding steps to mitigate the same is crucial in order to increase the effectiveness of the airline's maintenance program (Munna et al., 2018). While training issues were sometimes associated with unlicensed or newly-qualified personnel, experienced certifying engineers also reported incidents related to inadequate knowledge, skills or experience (Hobbs, 2008).

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) (Alomar & Jackiva, 2023). The content of the maintenance activities and the required specifications in terms of equipment and operators' skills are imposed by the international law (Stadnicka et al., 2017).

An interesting study by Delicado, Salado and Mompó (2018), aimed to assess the inefficiencies in collaborations between engineers working in the aircraft industry (Airbus) and to capture the effectiveness of competencies towards the organization's performance (Dawood, 2022):

The key concepts abstracted from the scenarios described in the previous study are the following:

C-1 There must be a systematic way of identifying skill requirements for successful performance of the required activities and determining whether an individual possesses a particular skill.

C-2 The ability of individuals to perform the activities enabled by a particular skill may vary. There must be a systematic way of assessing activity performance and evaluating the quality of outcomes produced.

C-3 Different sources of information about individual's skills and competencies vary in degrees of trust and validity. There must be a systematic way of identifying credible sources of information (Dawood, 2022).

For military aviation, it is stated that the success of any flying unit depends on the availability of the right number of maintainers with the right skill sets and experience to meet mission requirements. Skills and experience are a result of training, and just as in pilot training, the cumulative knowledge that our most valuable and technically advanced maintainers require comes at significant expense over time. Without trained and skilful maintainers to generate aircraft, airpower is unsustainable, pilot training is impossible, and mission objectives are unachievable: "The Air Force shall support readiness objectives by maintaining equipment in optimum condition, assign skilled personnel necessary to support expeditionary air forces, and manage fleet health to ensure long-term capability of air and space equipment" (Department of the Air Force Policy Directive 21-1, 2003, pp. 1-2).

Current researchers have not given much attention to the direct effect of employees' competence on job performance and its internal mechanism yet (Dawood, 2022) such as Lack of Focus on Soft Skills: While technical expertise is often highlighted, there is a gap in literature focusing on the role of soft skills (e.g., communication, teamwork, problem-solving) in improving maintenance outcomes.

Impact of Emerging Technologies: With Industry 4.0 and advanced technologies being introduced (e.g., automation, AI, augmented reality), the skills required by engineers are evolving. However, there is limited research on how these new skills influence overall performance. Regional or Sector-Specific Data: Much of the existing research generalizes the aviation industry, but there is a gap in understanding how regional (e.g., Morocco) or sector-specific (e.g., MRO vs. airline vs. military) skill sets impact maintenance performance. Training and Development Programs: There is limited research on the effectiveness of current training programs in addressing both technical and non-technical skills. Additionally, the gap exists in understanding how continuous education affects long-term performance.

Quantitative Correlation: Many studies emphasize qualitative assessments of skills and performance, but fewer offer robust quantitative analysis correlating specific skill sets with measurable performance indicators (e.g., reduced downtime, cost efficiency).

There are some research questions:

1. Technical vs. Non-Technical Skills: What is the relative impact of technical skills versus non-technical (soft) skills on the overall performance of aircraft maintenance teams?
2. Evolving Skill Requirements: How do emerging technologies in aircraft maintenance (e.g., automation, AI, and robotics) alter the skill set required for maintenance engineers, and how does this impact overall performance?
3. Sector-Specific Skills: How do skill requirements and their correlation to maintenance performance differ between sectors (e.g., commercial airline maintenance, military aviation maintenance, MROs)?
4. Training Program Effectiveness: How effective are current training and development programs in preparing engineers with the necessary skills to optimize maintenance performance? What specific areas of training need improvement?
5. Quantitative Correlation: Can a quantitative correlation be established between the engineers' skill levels (both technical and non-technical) and key performance indicators (KPIs) such as maintenance turnaround time, safety compliance, and cost efficiency?
6. Regional Variations: How does the availability and quality of engineers' skill sets in different regions (e.g., Morocco's aerospace industry) influence the overall efficiency and performance of aircraft maintenance?
7. Skill Development and Sustainability: What is the long-term impact of continuous education and upskilling initiatives on the sustained performance of aircraft maintenance?

II. RESEARCH METHOD

The article adopts a quantitative approach based on the collection of data from aircraft maintenance technicians, using questionnaires developed for this purpose (Appendix 1), the validity of which was confirmed by specialists in the field and the reliability tested using statistical instruments. The subjects of this study were 90 respondents comprising the three main maintenance professions, namely engineers, technicians and managers.

The research instrument is based on the performance of aeronautical maintenance with five aspects which are: accidents, incidents, delays, errors, and quality of management. The performance of maintenance technicians is based on six aspects: morale, experience, skills, stress, communication and safety.

The sample was determined using the Isaac and Michael calculation formula (Isaac & Michael, 1995). Data were analyzed quantitatively using canonical correlation analysis. This method was used to quantitatively examine the data the nature of the relationship between two blocks of variables as illustrated in the Figure 1.

In order to cover the aspects of the subject, the searchers identify the variables in Table 1.

The reliability of a measuring instrument refers to the consistency and stability of the results obtained when it is administered at different times or to different groups of people (DeVellis & Thorpe, 2021). In other words, a questionnaire is considered reliable if it produces similar results under similar conditions. There are many factors of reliability including Cronbach's KMO-alpha index. When the latter approaches 1, the measuring instrument is considered reliable. In our case, the Cronbach index is equal to: 0.880 as indicated in table 2. This means that the reliability of our measuring instrument is justified.

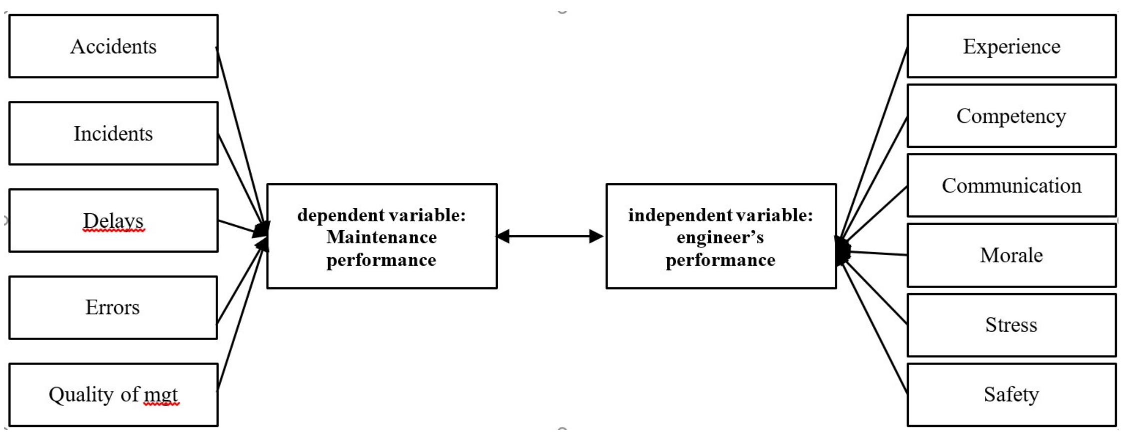

Figure 1. Dependent and independent variables

Table 1. Identification of the variables

Bloc	Variable	Measure
MP	Accidents	Number of accidents occurring on planes
MP	Incidents	Number of incidents recorded
MP	Delays	Volume of delays recorded
MP	Errors	Number of maintenance errors
MP	Quality of management	rating from 1 to 5
EP	Experience	Number of years in this field
EP	Skills	Number of years of study
EP	Communication	Number of languages spoken
EP	Morale	rating from 1 to 5
EP	Stress	rating from 1 to 5
EP	Safety	rating from 1 to 5

Table 2. Reliability statistics

Cronbach Alpha	Cronbac Alpha based on standardized items	Number of Items
.880	.830	7
Source : SPSS software		

Table 2. Parameters description

Parameter	N	Minimum	Maximum	Mean	Std Deviation
Number of accidents	90	0.000	3	1.189	1.0374
Delay in hours	90	2.000	13	7.622	2.5333
Number of errors	90	0.000	2	0.778	0.6996
Number of incidents	90	0.000	4	1.511	1.0731
Quality of management	90	2.000	5	3.844	0.8468
Experience	90	5.000	15	8.644	2.5673
Study	90	2.000	5	3.433	0.9721
Language spoken	90	1.000	3	1.989	0.7569
Level of safety	90	3.000	5	4.522	0.585
Level of stress	90	2.000	5	2.967	0.8799
Level of Morale	90	2.000	5	3.933	0.8715
Valid N (listwise)	90				

Table 3. Test of normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Number of Accidents	,217	90	,200	,853	90	,230
Delays in hours	,097	90	,236	,976	90	,100
Number of Erreurs	,247	90	,200	,791	90	,290
Number of Incidents	,194	90	,200	,900	90	,190
Quality of managment	,217	90	,200	,859	90	,200
Experience	,128	90	,201	,942	90	,301
Study	,209	90	,200	,878	90	,220
Languages spoken	,217	90	,200	,809	90	,210
Level of Safety	,360	90	,200	,702	90	,240
Level of Stress	,231	90	,200	,833	90	,210
Level of Morale	,202	90	,200	,844	90	,150

a. Lilliefors Significance Correction

III. Result and Discussion

Descriptive Analysis

Descriptive statistics show a diversity of trends in the variables studied as shown in table 3. On average, accidents (1.189), errors (0.778) and incidents (1.511) remain infrequent, although there is some variability, particularly for incidents (standard deviation 1.0731). Delays reach an average of 7.622 hours, indicating significant variation between cases (standard deviation of 2.5333). The quality of management (3.844), the level of safety (4.522) and morale (3.933) are judged rather positively, while stress has a moderate average of 2.967. The levels of experience (8,644 years) and education (3,433 on a scale of 2 to 5) show a relatively qualified and diverse population. Finally, languages spoken (1,989 on average) confirm that most individuals

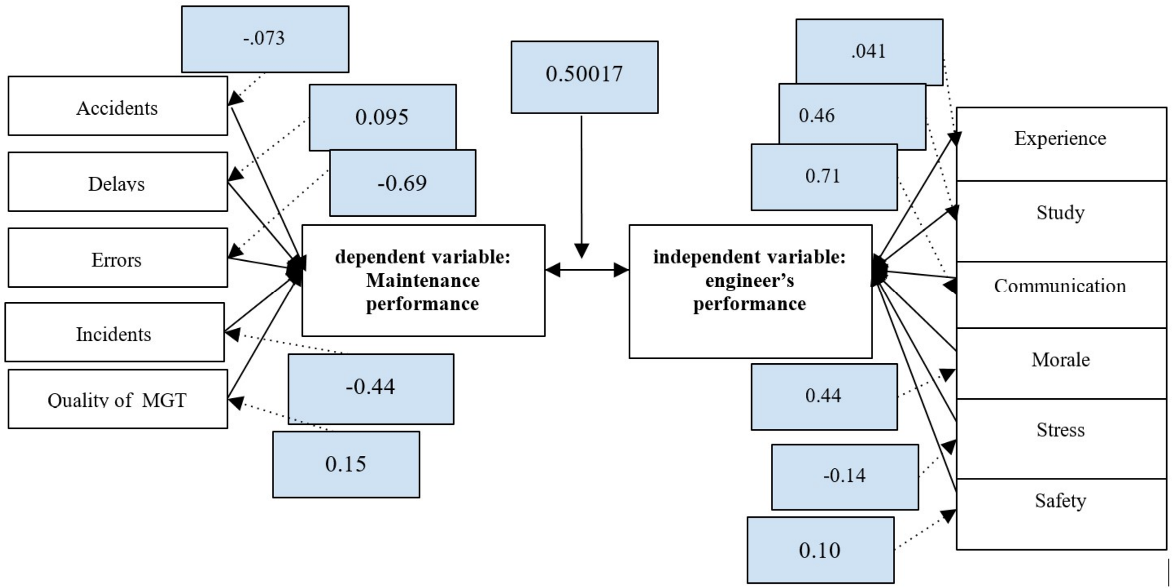

Figure 1, Canonical correlation coefficients (Source: SPSS results)

speak one or two languages, which can contribute to the overall cohesion and skills of the group. These data show elements of stability and diversity in experiences and perceptions, suggesting varied aspects of satisfaction and competence in the sample.

Prerequisite test

The analysis of canonical correlation is carried out under the assumption of three conditions, namely normality (Table 4), linearity and multi-collinearity. The tests carried out on our database show that the distribution of the data is normal, because the Kolmogorov-Smirnov test, used for the normality test, gave a result of P>0, which is greater than 0.05. When p>0.05 and the value of F Fcount r table is present, the linearity test uses the F coefficient test with guidelines. The data distribution is considered normal because the p-value for the variables is 0.200, or 0.200>0.05, according to the calculations.

Hypothesis test

The analysis of the observations using the SPSS software, using the MANOVA function, allowed us to obtain the coefficients of the two blocks of variables, as illustrated in the Figure 2.

The analysis of canonical correlations shows that there is a positive relationship between the performance of aeronautical maintenance and that of maintenance technicians. This means that the improvement of the performance of aeronautical maintenance technicians leads to an increase in the performance of the aeronautical maintenance function. However, according to the calculations, this positive correlation remains relatively low, with a value of 0.50017.

Regarding the correlations of the variables involved in the construction of the independent variable, the variable "communication" seems to play a determining role in the performance of aeronautical maintenance technicians. Experience, morality and the number of years of study also contribute, but less markedly, to the performance of aeronautical maintenance. On the other hand, the results suggest that stress and the level of safety do not influence the performance of technicians. The results obtained are consistent with those of previous research. In this sense, we cite the study of (Chatzi & Kourousis, 2024) which confirmed the effective role of communication between maintenance technicians in the success of aircraft maintenance operations. Likewise, for the great place of human factors namely morality or psychological state, experience and skills in the quality of aeronautical maintenance interventions (Li et al., 2008). Contrary to all expectations, the results obtained indicate that the level of feeling of security and the level of stress of maintenance technicians have no impact on the effectiveness of aircraft maintenance. Although most studies confirm the existence of a positive link between the feeling of security, stress and the quality of maintenance interventions, some research also highlights the neutrality of this factor. As an example, we can cite the work of (Wiegmann & Shappell, 1999).

IV. Conclusion

The findings from this study emphasize that enhancing the competencies of maintenance personnel can lead to meaningful improvements in aircraft maintenance performance, highlighting specific areas such as communication, experience, and morale as pivotal to reducing incidents and increasing operational efficiency. While technical expertise remains essential, the significant impact of interpersonal skills and experience underscores a shift towards valuing human factors in maintenance strategy.

For managers and policy-makers in the aviation industry, these results suggest that a balanced approach to technical and soft skills training could yield substantial benefits. In particular, initiatives that foster better communication and morale may serve as cost-effective measures to improve maintenance outcomes without needing extensive changes to operational procedures. The neutral impact of stress and safety perception indicates that additional research could clarify their roles in specific contexts, such as high-stress environments or under varying regulatory conditions.

Moreover, this research suggests that targeted recruitment and training strategies focused on these identified competencies could help maintenance organizations better navigate the demands of Industry 4.0, where automation and human-machine collaboration are growing. As maintenance organizations face increasing technological integration, investing in human capital that aligns with these critical competencies may serve as a competitive advantage. Future studies could further investigate the influence of these factors across various industry segments, such as commercial aviation, military operations, and MROs, to identify specific strategic approaches within each segment.

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