Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 2 (2023)

Statistical Analysis of Production Planning Impact on Aircraft Maintenance Turnaround Time by Exploring Challenges During Work Package Preparation

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Abstract
Preplanning all routine work is universally accepted as essential for smooth execution. This fact is well-proven and equally valid throughout all industries but more precisely in the operations and maintenance domain. An emphasis is placed on production planning and aircraft maintenance work-packaging in this research paper. Almost all sorts of maintenance work performed on any aircraft are transcribed as maintenance procedures by the manufacturer. It makes production planning work smooth and easygoing while preparing the aircraft maintenance work packages. However, significant challenges during package preparation are unavoidable and may surprise planners at the last minute. An extensive understanding of the process, stakeholders, and consequences is imperative to minimize surprises. This paper will highlight all these areas to provide detailed insights about work packaging.
***Keywords** : Aircraft Maintenance Management; Work Packaging; Production Planning; Airlines Management; MRO Management; Turnaround Time; Maintenance Optimization.*

Introduction

The aircraft maintenance work is comparatively complex due to the involvement of advanced and sensitive technologies [1]. All the systems, equipment, and major assemblies are state-of-the-art and made to prove reliable and durable. To maintain the intended purpose of the aircraft and its components, the execution of scheduled maintenance per timelines and procedures given by the aircraft or component manufacturer is essential [16]. Complete scheduled maintenance activities that must be performed on aircraft come from the manufacturer in the form of a maintenance planning document (MPD) [8]. At the aircraft operator or owner level, MPD is jotted down as per applicable aircraft type of fleet and becomes an aircraft maintenance program (AMP) [10] [11]. Some other sources also provide input during AMP preparation, such as, regulatory authority, operational experience, reliability monitoring program, Extended-range Twin-engine Operations Performance Standards (ETOPS) program, and others [14].

Upon completion of AMP, it is submitted to the aviation regulatory authority for approval to ensure that the content inside it is aligned with international airworthiness standards. An approved AMP is established as the baseline to perform maintenance on the aircraft as per the interval given [9]. AMP is being tracked and controlled using enterprise resource planning (ERP) or other similar tools based on the type of organization. It is mainly to maintain the aircraft maintenance record, capture the last carried out details and generate maintenance forecasts [16].

Based on the maintenance forecast, a scheduled maintenance plan is established [15]. It could be a short-term maintenance plan, mid-term maintenance plan, long-term maintenance plan, and heavy maintenance plan [13] [18]. A qualifying criterion for each of these plans could be different, but the baseline is that the short-term plan caters to maintenance falling due within 12 months, the mid-term is for 1-3 years, and the long-term is for 3-5 years. Once the scheduled maintenance plan is confirmed, the maintenance planning team starts preparing the work scope of the maintenance checks: Interim (INT) checks, Service Checks (SV), A-Checks, and C-Checks [10].

Upon receiving the green light from maintenance planning about upcoming checks, production planning starts working on the work packages by considering all the resource requirements and constraints associated with it [16]. This research paper focuses on production planning activities and highlights challenges during work package preparation. This mainly provides researchers and industry professionals with a broader view of the significance of production planning and addressing the challenges.

A. Objective

A major objective of this research paper is to highlight critical aspects of production planning in contrast with aircraft maintenance package preparation. This research paper will also provide complete familiarization about the process in an elaborate and straightforward manner possible.

B. Need of Study

Aircraft maintenance workflow mainly depends on how the production planning team prepares the aircraft maintenance work package, which makes it imperative to have a highly optimized work package [21]. This study centers on the challenges during work package preparation which significantly impacts aircraft maintenance. Highlighting such challenges will help the aviation industry.

C. Scope of Study

This research paper is mainly driven by an rigorous literature review of well-published studies and reviews from senior managers working in airlines and maintenance repair and overhaul (MRO) organizations. This research paper primarily focused on preparing aircraft maintenance work packages by the production planning team and its impact on aircraft maintenance downtime.

D. Limitation

This study only concentrates on preparing aircraft maintenance work packages by production planning within airlines and maintenance repair and overhaul (MRO) organizations.

E. Background of Study

Across the globe, airlines and MRO organizations adhere to two primary types of aviation regulations primarily governed by the European Union Aviation Safety Agency (EASA). These regulations are referred to as Part-M and Part-145 (see Figure 1) [13] [14]. While these regulations might carry slightly different names in various countries, their underlying frameworks remain primarily identical.

Figure 1 - Type of aviation regulation for continuing airworthiness

Part-M organizations are commonly referred to as Continuing Airworthiness Management Organizations (CAMO) [8]. From an aircraft maintenance standpoint, CAMO is responsible for formulating the Aircraft Maintenance Program (AMP) and securing its endorsement from the country's civil aviation authority. After the aviation regulator approves, the AMP is converted into a maintenance tracking format to oversee maintenance projections and generate resource prerequisites.

As and when maintenance falls due, CAMO personnel will define the scope of work for either the aircraft or its components. The same work scope will be communicated to the production planning, which comes under the purview of Part-145 regulations (see Figure 2) [7]. Leveraging the defined work scope, the Part-145 team will secure resource readiness and subsequently carry out the maintenance tasks.

Figure 2 - Relationship between Part-M and Part-145

Aircraft maintenance primarily consists of two segments: line maintenance and base maintenance (see Figure 3). Line maintenance encompasses minor tasks such as Line Replaceable Unit (LRU) handling, minor inspections, and finite troubleshooting of snags, which can be executed without hangar access. In contrast, base maintenance necessitates hangar facilities for conducting major tasks. Examples of major tasks include extensive maintenance checks, primary assembly replacements, aircraft jacking, and other complex procedures [20] [22].

Types of Aircraft Maintenance	
Line Maintenance - Minor Inspection - LRU replacement - Minor troubleshooting - Other minor work	Base Maintenance - Major inspection - Major assembly change - Aircraft stripping - Aircraft jacking

Figure 3 - Types of Aircraft Maintenance

The maintenance conducted on the aircraft is primarily guided by maintenance work packages devised by the production planning team [13]. This team is responsible for crafting work packages for all aircraft maintenance activities. Several factors are involved in producing maintenance work packages. Each one presents a unique challenge. This research article sheds light on such challenges encompassing the preparation of maintenance work packages.

Literature Review

Aircraft maintenance work packages have been in practice for quite a long time, while they were created manually by writing on paper. Since then, much technological advancement has commenced, and it is now being generated from resource planning programs adopted by the organization as per business needs [15]. However, most airlines and MRO use enterprise resource planning (ERP) programs to do those jobs.

Soon after aviation regulators approve AMP, all the scheduled maintenance tasks in AMP are uploaded into the ERP program. It is fed with details, primarily maintenance task frequency, tolerance, last carried out details (if any), next-due details, and resource requirements [16]. After receiving above mentioned input, ERP starts generating the maintenance forecast. Based on the maintenance forecast, work packages are created.

When crafting aircraft maintenance work packages, five critical factors necessitate careful consideration. This begins with the initial estimation of resource requirements, followed by simulating workflow dynamics and evaluating the required budget [22]. Figure 4 comprehensively depicts these five pivotal factors.

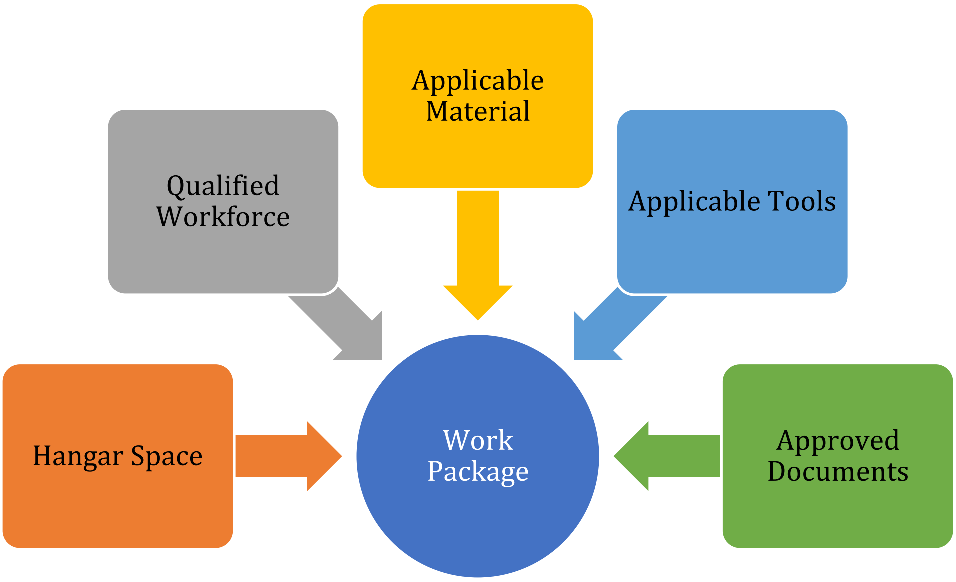


Figure 4 - Factors to be considered during work package preparation

Challenges associated with each of these factors are comprehensive and mentioned in the following paragraphs in an elaborated manner to improve the understanding and significance within the aircraft maintenance environment. However, challenges are broader than the factors mentioned earlier, and they may be more. Nevertheless, this research papers primarily focus on challenges from a work package preparation perspective.

A. Aircraft Maintenance Hangar Space

A hangar space is essential to perform base maintenance activities on an aircraft [5]. Depending on the scope of work, hangar duration is decided by the production planning personnel [1]. For example, A-check, Interim (INT), or service check on airliner aircraft may require hangar space for 24 to 48 hours. On the other hand c-check on an airliner aircraft may require at least 15 days to 45 days of grounding, depending on the type of C-check [12]. An airline operating with a fleet size of 72 airliner aircraft, which requires a C-check to be performed every two years with a minimum grounding of 20 days, may require at least two hangars to cater to the demand (refer to equations 1 and 2).

$$\frac{\text{Total no.of days in a year (d)}}{\text{Grounding days per aircraft (g)}} = \text{Y} \qquad (1)$$

Here 'Y' refers to the total number of hangar slots available in a year, 'd' represents the total number of days in a year, and 'g' represent grounding need per aircraft. This calculation considers that all aircraft and C-Check time is the same to imitate the grounding duration.

$$\frac{365\ (\text{d})}{20\ (\text{g})} = 18.25\ (\text{Y}) \qquad (2)$$

Above mentioned equation number 2 shows that in a year, one hangar could accommodate a maximum of 18 aircraft with the condition of no deviation or extension of maintenance grounding. In such calculation, within two years maximum C-check a hangar can handle is only 36. However, an organization must refrain from grounding all aircraft simultaneously to perform C-check. To cater to such issues, an aircraft staggering plan is used to achieve maximum utilization of aircraft before the C-check grounding. Based on the calculation as per equations 1 and 2, an organization will require at least two hangars to cater c-check demand of 72 aircraft in two years.

The calculation mentioned above is based upon zero deviation occurrence. However, when ten aircraft out of 72 are comparatively aged, it is improbable to come up without significant non-routine findings during C-check inspection. In such cases, aircraft grounding duration will increase, affecting the whole planning. Therefore, identifying the optimal grounding duration for the aircraft to generate hangar demands is very challenging [4]. An advanced state of art data analytics tool could be very helpful in such a scenario to optimize aircraft grounding duration by imitating real challenges [21].

B. Qualified Workforce

The aviation industry is known for its highest safety standards, which are regulated and monitored by the aviation regulatory authorities at the national and international levels. Airlines and MRO also follow the same philosophy and regulate employees working at aircraft maintenance hangars and other related functions. Human resources required to work on an aircraft are licensed personnel [2]. An engineer working on an aircraft must have an aircraft maintenance engineer's (AME) license issued by the aviation regulatory authority of the country of aircraft registration. Additional to the license, several mandatory training needs to be completed and monitored by the aviation regulators [7]. Similarly, all other staff, including aircraft technicians, must have the required experience, training, and authorization as per the nature of their work.

In such a controlled environment, a production planning team must have a highly optimized workforce allocation plan with maximum productive hours [2]. Achieving optimal productivity is a challenging task with its limitations, which are yet to be cracked [19]. It becomes challenging when an aircraft undergoing major maintenance checks encounters severe defects requiring maintenance personnel from multiple engineering trades. In such a case, people are being pulled up from ongoing projects and allocated to newly found challenges, which will affect the maintenance grounding timeline for another aircraft [3]. Therefore, catering to such unforeseen circumstances creates challenges that most organizations face. Many manufacturers have started using live health monitoring systems, limited to only a few major assemblies and systems. A similar system applicable to the whole aircraft could be more beneficial for the industry because it will help the production planning team to simulate upcoming failures to allocate and budget workforce in advance.

C. Applicable Material

All aircraft maintenance work requires a significant amount of spares to perform the maintenance work on the aircraft. Knowing such requirements is essential to make prior arrangements to complete the maintenance. Schedule maintenance requirements, which are forecasted well in advance, are helpful for budgeting and forecasting spares and materials [7]. During work package preparation, the production planning team ensures that all material-related requirements are taken care of before scheduling an aircraft for maintenance. Maintenance requirements are not limited to spares, rotatable, expendables, consumables, and other similar items.

Recently, due to the COVID-19 issue, many aviation equipment manufacturers and vendors have closed or exited the aviation business, creating a vacuum in the aviation material supply market [17]. Soon after air travel restrictions were lifted, all aircraft owners and operators wanted to bring their aircraft back into the sky.

However, due to the limited supply of spares, bringing aircraft return to service takes time and effort [10]. In such challenging circumstances, ensuring material requirements prior to aircraft induction to maintenance is challenging and forces the production planning team to come up with innovative solutions [19].

Another challenge is the timely and cost-effective arrangement of spares and materials. Prediction of optimum utilization of installed spares and cost-effective replacement is an exciting thing to be considered during work package preparation [17]. Big airlines or MRO may maintain their inventory to overcome challeneges related to major assemblies' replacement, but small organizations face significant challenges due to high inventory costs [12]. In such a cost-effective environment, the production planning team must make alternate arrangements, including an overhaul-exchange contract with a vendor or a rental agreement with suppliers. Such an arrangement could be very exhaustive and require significant effort.

The third challenge faced by production planning during work package preparation is human error. Due to human mistakes, if some items are not included in the prior calculation or are miscalculated may cause a shortage of material during maintenance, and such issues are common [1]. Such challenges could be overcome by utilizing checkpoints or filters at multiple levels.

The fourth type of significant challenge is the items with high lead time. Such items may take longer than anticipated, mainly due to a limited number of suppliers available in the market. In such cases, work packages are prepared considering suppliers' promised delivery of spares, which cannot be met sometimes and significantly increases aircraft downtime. Such challenges can be addressed by effectively employing 3-D printing technologies [10].

D. Applicable Tools

In an aircraft maintenance environment, correct and applicable tools availability is imperative. It is mainly because of safety-oriented maintenance requirements, involvement of human lives, and high cost [10]. For example, a tow bar used for a small business jet may not be advisable to tow a narrow-body airliner aircraft, and it may break down while towing is in progress and lead to an incident or accident.

Therefore, for each type of maintenance requirement, aircraft or equipment manufacturers defines the tools required to perform the maintenance task and identified by the part numbers. Some of such tools require calibration and certification at given time intervals. It creates challenges for the production planning team during work package preparation because each time during package preparation, a separate tracking of calibration validity during maintenance is imperative and require innovative technologies, such as, Radio-Frequency Identification (RFID) [19].

The second significant challenge during work package preparation is the prior arrangement of special tools. Due to the infrequent use of such special tools, high cost and frequent maintenance requirements make it an expensive affair for small airlines or MRO. It can be challenging for the production planning team to secure the timely availability of such tools during aircraft maintenance inputs during work package preparation. In such cases, pooling arrangements among airlines and MRO could be a solution.

The third challenge experienced by the production planning team during work package preparation is ensuring the timely availability of ground service equipment (GSE) [10]. The ground power unit (GPU), tow truck are some examples of GSE items. Some big airlines or MRO have a dedicated team to maintain GSE, but smaller organizations cannot afford it. During work package preparation, the production planning team ensures the availability of GSE during aircraft maintenance input. Sometimes, due to the maintenance issue and limited availability of GSE items, it becomes challenging for the production planning team to secure them. Such trouble could be avoided by making long-term scheduled maintenance plans and GSE support agreements among nearby organizations [6].

E. Approved Documents

All the maintenance work on the aircraft follow the approved maintenance documentation [8]. It can be in the form of procedures originating from the aircraft maintenance manual (AMM), work instructions, job cards, work orders, engineering orders, checklists, or other similar documents. During preparing aircraft maintenance work packages, the production planning team ensures that the latest revision of technical manuals is incorporated to ensure effective airworthiness compliance [4].

A work package is a combination of several aircraft maintenance work orders. For a C-Check, these work orders may come from various aircraft zones. The inclusion of maintenance work orders is defined based on the work package type. A C-Check package may include all upcoming scheduled maintenance tasks until the next c-check, along with deferred defects, major modifications, and system upgrades. During the preparation of work packages, the key points to be considered are the inclusion of all upcoming scheduled maintenance tasks (as per applicability), deferred maintenance tasks, major modifications, airworthiness directives (ADs), service bulletins (SBs), and other critical maintenance requirements [3].

While preparing the work package, the challenge experienced by the production planning team is to filter work orders with incorrect information, which requires correction. Some common errors highlighted by previous researchers are not limited to wrong AMM reference, incorrect part number and quantity of material and tool, and missing maintenance steps. Therefore, preparing an error-free work package requires extensive reading of each work order by the planning team. If the errors are discovered later during audits, they may cause significant setbacks for the organizations. The detailed review of work orders is also essential to obtain the number of man-hours needed to complete each task so that human resource budgeting can be accomplished.

A detailed review of the work package is also required to prepare a Gantt chart using MS project to allocate resources, set up milestones, and track progress. It also helps the production planning team evaluate critical paths and assign parallel activities to achieve the shortest possible aircraft grounding for maintenance.
To meet all the aforementioned parameters, it is imperative to establish a production planning team that possesses technical expertise and substantial experience.

Research Methodology
The research methodology employed for this paper undergoes five distinct stages, as depicted in Figure 5. It commences with formulating the problem statements, followed by conducting a literature review, designing a survey, collecting data, and ultimately analyzing the data using the statistical tool of multiple regression.

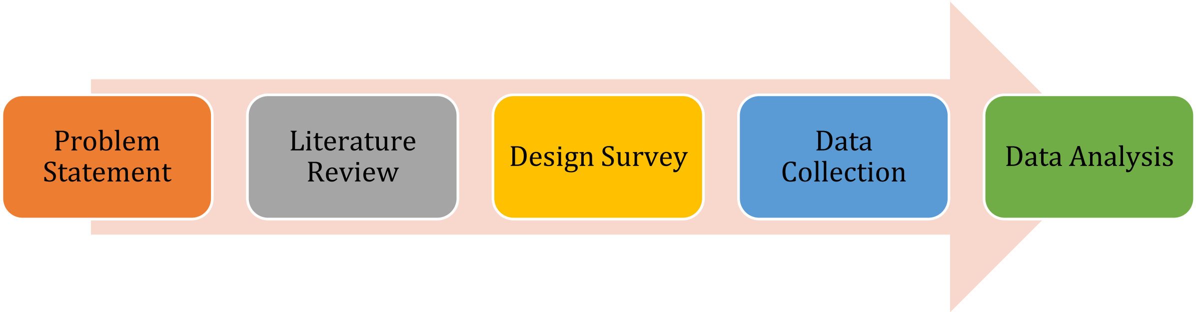


Figure 5 - Research Methodology Framework

This research paper underscores the importance of the production planning team's role by focusing on a critical aspect: work package preparation. The author conducted multiple discussions with professionals in the MRO and airline industries about production planning to gain further insights. Guided by the literature review outcomes and these discussions, a concise questionnaire comprising six questions was formulated to gauge the production planning team's impact on minimizing aircraft maintenance downtime. We distributed this questionnaire among seasoned aviation professionals to evaluate the importance of production planning within airlines and MRO organizations. Google Form is used to prepare the questionnaire and disseminate it among seasoned professionals within the aviation industry.

#	Table 1 - Statistics of Research Questionnaire	
	Type of Material	***Quantity***
1	Total questions included in questionnaire	6
2	Total questionnaires distributed to Airlines and MRO professionals	8000
3	Total response received from Airlines and MRO professionals	7719
4	Percentage of responses received from Airlines and MRO professionals	96.5%

A sample size of 8,000 is planned for this study, and conventional sampling calculation techniques are used. The researcher has arrived at this sample size by considering the Confidence Level at 95.00 %, Population Proportion of 0.5, Marginal Error of 1.0%, and Population Size of 100,000. A statistical summary of the research survey in Table 1 shows that the questionnaire was distributed among 8,000 aviation professionals. Three of the six questions were administered using a linear scale, forming both dependent and independent variables (see Table 2). The remaining trio of questions served as demographic queries designed to verify the authenticity of respondents (see Chart 1, Chart 2, and Chart 3). A strong emphasis on professional ethics and data integrity is maintained throughout the data collection and analysis stages.

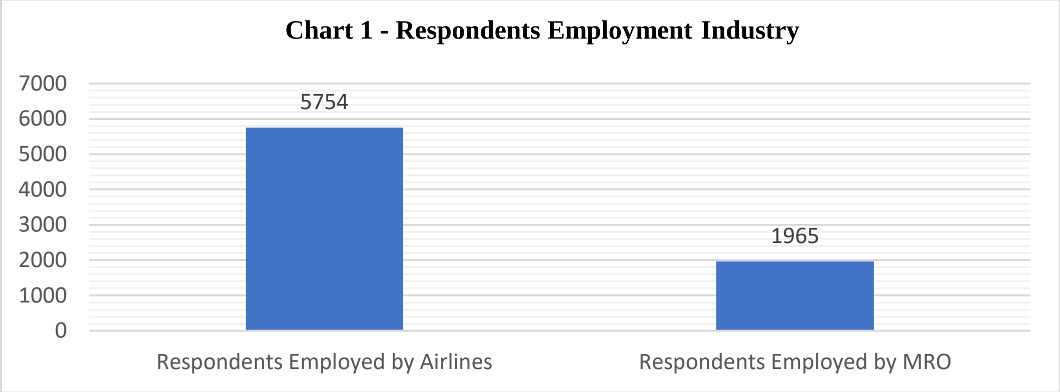


Chart 1 shows that most respondents belong to airlines and 5754 in numbers. They are followed by respondents working in the MRO industry and 1965 in numbers.

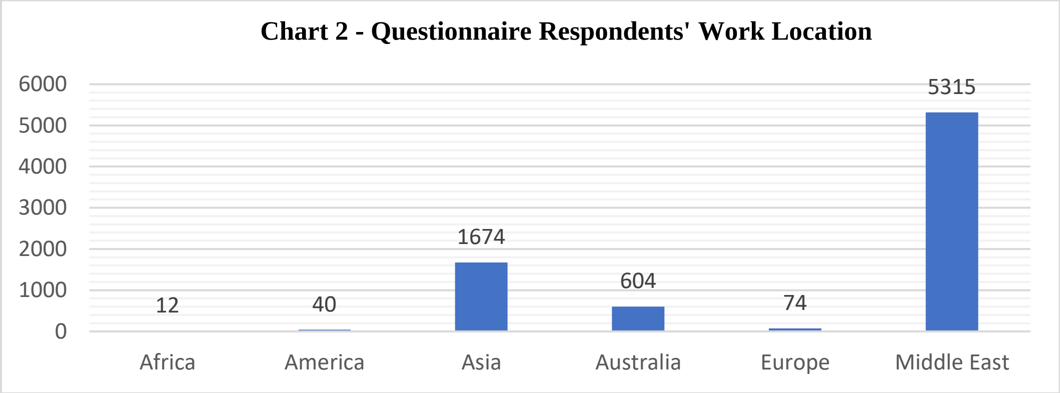
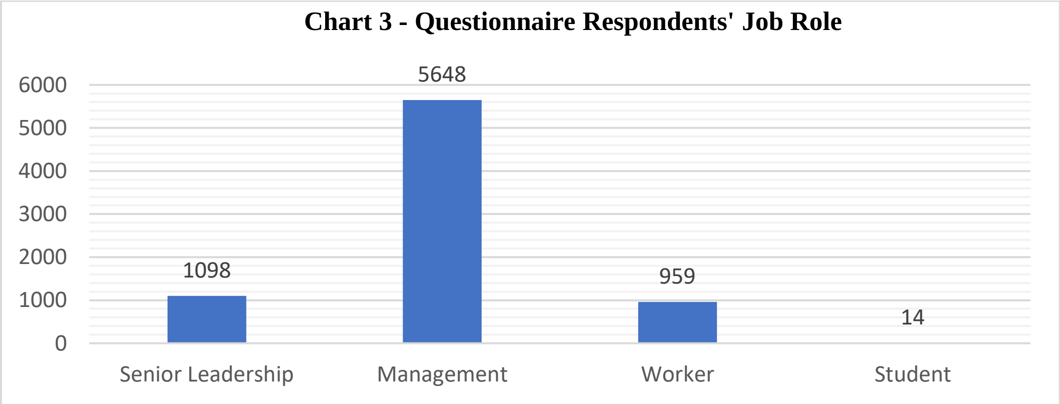


Chart 2 shows that most respondents are employed in the Middle East region, followed by the Asian region and Australian region. However, only a few professionals contributed from the African region.



According to chart 3, out of all 7719 respondents, 5648 hold management positions, followed by 1098 in senior leadership roles and 959 as workers. However, only a few students (14) participated in this study who are doing an internship in airlines or MRO.

The data analysis functionality of MS Excel was utilized to conduct multiple regression, yielding regression statistics, an ANOVA summary, and a model summary as outcomes.

Results

The process of data analysis unfolds through five essential stages, detailed in figure 6. It initiates with response analysis and advances to data cleaning. Upon completion of data cleaning, the data analysis functionality of Microsoft Excel is employed to conduct multiple regression between the dependent and independent variables.

The ensuing outcomes of the regression are subsequently interpreted to evaluate the influence of production planning on the reduction of aircraft maintenance turnaround time. This method contributes to the development of a functional model equation (3).

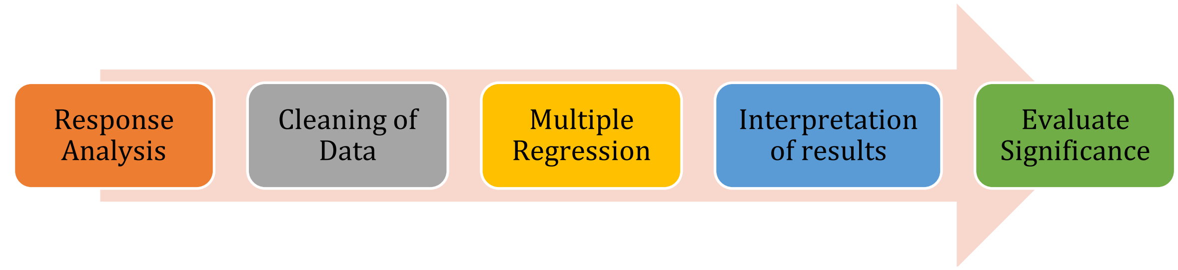


Figure 6 - Steps Followed During Data Analysis

List of independent and dependent variables used in analysis are mentioned in Table 2. A total of two independent variables were analyzed in relation to a singular dependent variable.

#	**Table 2 - Statistics of Research Questionnaire**	
	Description of Questions	*Variables*
1	It is vital to reduce aircraft maintenance downtime.	Dependent
2	Aircraft downtime can be reduced through proactive production planning.	Independent
2	The turnaround time can be significantly reduced through continuous improvement in production planning.	Independent

Based on data analysis outcome, regression statistics revealed some surprising facts as shown in table 3. R square value 0.7884 from model summary revealed that 78.84% of the variation of dependent variable is explained by the regression of indpendent variables.

Table 3 - Regression Statistics

Multiple R	0.887911
R Square	0.788387
Adjusted R Square	0.788332
Standard Error	0.239718
Observations	7719

Further review of the ANOVA summary (table 4) shows that the regression equation is highly significant with an F value of 14373.37, P < 0.01.

It shows that the regressional equation model proves that production planning play a crucial role in the airlines and the MRO industry to reduce aircraft maintenance downtime.

Table 4 – ANOVA Summary

	df	SS	MS	F	Significance F
Regression	2	1651.924	825.9619	14373.37	0
Residual	7716	443.3979	0.057465		
Total	7718	2095.322			

Additionally, as shown in table 5, the regression coefficient summary shows that all independent variable is highly related.

Table 5 – Regression Coefficient Summary

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.4488	0.0261	17.2216	0.0000	0.3977	0.4999
Aircraft downtime can be reduced through proactive production planning.	0.5457	0.0138	39.6522	0.0000	0.5187	0.5727
The turnaround time can be significantly reduced through continuous improvement in production planning.	0.3614	0.0134	26.9471	0.0000	0.3351	0.3877

Data interpretation of the coefficient summary table gives an equation and shows the importance of production planning in reducing aircarft maintenance downtime.

$$Y = 0.5457*x + 0.3614*z + 0.4488 \qquad (3)$$

As per equation (3), x represents proactive production planning, and z refers to continuous improvement in production planning. Data interpretation revealed that aircraft maintenance downtime could be reduced significantly by proactive production planning and continuous improvement in it.

Discussion And Recommendations

A typical multiple regression was executed between the dependent and independent variables to assess the importance of production planning, particularly in the context of work package preparation within the airline and MRO sectors. The results substantiated this assertion, emphasizing the pivotal role of production planning. Considering work packaging as a primary function of the production planning team and data analytics results demonstrates favorable outcomes.

It revealed that emphasizing the proactiveness of production activities, continuous improvement in work packaging, and employing the suggestions mentioned in the literature review could help airlines and MROs minimize aircraft maintenance downtime, resulting in improved productivity and profitability. This study can further be extended to identify digital tools to automate the process to its full extent to improve productivity and minimize challenges. This study can also be utilized and extended to IT professionals to develop an automation tool that will cater to the challenges highlighted in this research paper.

Conclusion

This research illustrates the essential nature of aircraft maintenance work package preparation for the production planning team, highlighting the substantial challenges inherent in packaging within airlines and the MRO sector. Noteworthy findings underscore that proactivity and ongoing enhancement are pivotal factors from the production planning standpoint, directly contributing to reducing aircraft maintenance turnaround time. The challenges elucidated in this research paper are comprehensive and warrant earnest consideration. An assertive approach to addressing these issues will empower organizations to attain heightened levels of success.

Acknowledgment

The research was conducted with unwavering and continual assistance from Banasthali Vidyapith University (India). The researchers extend heartfelt gratitude for the invaluable support extended by each Subject Matter Expert (SME) and aviation professional who participated in the study.

Disclosure Statement

This research paper's author(s) affirm that they do not possess any pertinent or substantial financial interests pertaining to the research elucidated in this paper.

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