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TAGUCHI METHOD-BASED MAN-HOUR OPTIMIZATION FOR BOEING 777 A-CHECK INTERVAL

BOEING 777 A-BAKIM ARALIĞI İÇİN TAGUCHI METODU TABANLI ADAM-SAAT OPTİMİZASYONU

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Abstract

Aircraft maintenance is critical for safety and operational efficiency. For the Boeing 777, A-checks are conducted every 1000 flight hours (FH), resulting in five checks per aircraft annually, with significant downtime and labor costs. This study proposes a Taguchi method-based man-hour optimization model extending the A-check interval to 1500 FH and reducing the number of annual checks while maintaining safety and regulatory compliance. The analysis carried out in this study revealed significant benefits of this interval extension. Annual downtime for the 12-aircraft fleet decreased from 60 to 40 days, allowing 20 additional operational days and generating $1 million in extra revenue. Labor costs were also reduced, with annual man-hours dropping from 1586 to 1153 per aircraft, saving 5196 hours fleet-wide. This optimization translates to $416.000 in labor cost savings annually, with a total financial benefit of $1416 million. Redistributing tasks between A- and L-checks further enhanced efficiency. Tasks such as lubrication and minor inspections were consolidated, and comprehensive cabin cleaning at 1500 FH was supplemented with intermediate cleaning at 500 FH to maintain passenger experience. These adjustments balanced the workload without affecting turnaround time or safety. This optimization demonstrates the potential for significant cost savings and operational improvements in aviation maintenance. Extending the A-check interval increased fleet availability, reduced labor requirements, and ensured compliance with regulatory standards. The findings highlight the importance of strategic maintenance planning and the potential for similar optimizations across other aircraft types and fleets.

Keywords: Optimization, aviation, aircraft maintenance, Taguchi method.

Öz

Uçak bakımı, emniyet ve operasyonel verimlilik açısından kritik öneme sahiptir. Boeing 777'de A-bakımları her 1000 uçuş saatinde (Flight Hours-FH) bir yapılmakta, bu da uçak başına yılda beş bakım yapılmasına neden olmakta ve önemli arıza süreleri ve işçilik maliyetleri ortaya çıkmaktadır. Bu çalışma, Taguchi yöntemi tabanlı bir adam-saat optimizasyon modeli önererek A-bakım aralığını 1500 FH'ye çıkarmakta ve emniyet ile mevzuata uygunluğu korurken yıllık bakım sayısını azaltmaktadır. Bu çalışmada gerçekleştirilen analiz, bu aralığın uzatılmasının önemli faydalarını ortaya koymuştur. Yıllık arıza süresi 12 uçaklık filo için 60 günden 40 güne düşerek 20 ek operasyonel gün ve 1 milyon dolar ekstra gelir elde edilmesini sağlamaktadır. İşçilik maliyetleri de azalmış, uçak başına yıllık adam-saat 1586'dan 1153'e düşerek filo genelinde 5196 saat tasarruf sağlanmıştır. Bu optimizasyon, yıllık 416.000 dolarlık işgücü maliyeti tasarrufu ve toplamda 1416 milyon dolarlık mali fayda anlamına gelmektedir. Görevlerin A- ve L-bakımları arasında yeniden dağıtılması verimliliği daha da artırmıştır. Yağlama ve küçük denetimler gibi görevler birleştirilmiş ve yolcu deneyimini korumak için 1500 FH'deki kapsamlı kabin temizliği 500 FH'deki ara temizlik ile desteklenmiştir. Bu ayarlamalar, geri dönüş süresini veya güvenliği etkilemeden iş yükünü dengelemiştir. Bu optimizasyon, havacılık bakımında önemli maliyet tasarrufu ve operasyonel iyileştirme potansiyelini ortaya koymaktadır. A-bakım aralığının uzatılması filonun kullanılabilirliğini artırmış, işgücü gereksinimlerini azaltmış ve düzenleyici standartlara uygunluğu sağlamıştır. Bulgular, stratejik bakım planlamasının önemini ve diğer uçak tipleri ve filolarında da benzer optimizasyonların yapılma potansiyelini vurgulamaktadır.

Anahtar Kelimeler: Optimizasyon, havacılık, uçak bakımı, Taguchi metodu.

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1. INTRODUCTION

Aircraft maintenance is a cornerstone of the aviation industry, ensuring the safety, reliability, and efficiency of flight operations (Tyagi et al., 2023; Pop et al., 2023). Broadly, maintenance tasks are divided into periodic (scheduled) and non-periodic (unscheduled) maintenance (Sarhani et al., 2016). Periodic maintenance is meticulously planned and conducted at predefined intervals, encompassing routine inspections, system tests, and component replacements (Fu & Avdelidis, 2023; Karaoğlu et al., 2023). Non-periodic maintenance, on the other hand, is reactive, addressing unexpected issues such as component failures or damage due to external factors (Baptista et al., 2017; Ab-Samat & Kamaruddin, 2014; Lin et al., 2015).

Scheduled maintenance tasks are further categorized into A-, B-, C-, D-, E-, and F-checks based on their complexity (Pimapunsri & Weeranant, 2018) and frequency (Ahmadi et al., 2010). A-checks are performed most frequently, focusing on basic inspections, lubrication, and minor system adjustments (Ghobbar, 2010; Rao et al., 2017). B-checks are slightly more detailed and carried out every few months (Deng et al., 2020; van der Weide et al., 2022). C-checks involve comprehensive inspections and are performed every 18-24 months, requiring significant downtime (Kulkarni et al., 2017; Şentürk et al., 2010). D-checks, also known as heavy maintenance checks, are the most extensive, often involving complete disassembly of the aircraft and occurring every 6-10 years (Deng et al., 2021; Albakkoush et al., 2021; Mofokeng & Marnewick, 2017). E-checks are especially about heavy electrical maintenance. F-checks are fabricating level maintenance (Bowers et al., 2022; Yilmaz et al., 2010; Vieira & Loures, 2016).

Optimizing maintenance processes has become a critical focus for the aviation industry due to the substantial costs and operational implications associated with these tasks (Papakostas et al., 2010; Sriram & Haghani, 2003; Verhagen et al., 2023). Maintenance accounts for a significant portion of an airline's operating expenses, particularly in labor-intensive tasks (Korba et al., 2023). The need for optimization stems from the dual objectives of reducing costs and enhancing operational efficiency, all while maintaining strict adherence to safety and regulatory standards (Kabashkin et al., 2024).

Operators usually organize maintenance tasks for Boeing 777 aircraft into larger A-checks or more comprehensive basic checks at intervals of 500 FH, 200 FC, and around 60 days (Boeing, 2016, 2022). The maintenance program for Boeing 777 aircraft covers approximately 2000 tasks and 125 separate task intervals (Boeing, 2022). An average of 80-120 man-hours are required to complete them (Boeing, 2013). Emirates Airlines, headquartered in Dubai and owning 10% of the world's Boeing 777 fleet, began transitioning its Boeing 777 fleet of 154 aircraft to Boeing's optimized maintenance program (OMP) in early 2019 and performs all A-checks under this program. With this optimization, on-time takeoff and flight safety performance were determined to be at least 99,5%-99,6%. It also increased the availability and planned reliability of the aircraft (Boeing, 2008; Broderick, 2020).

For applicability of various methods for optimization of industrial processes, engineering design, and maintenance tasks, there are different decision-making and optimization techniques, such as machine learning (Karaoğlu et al., 2022), gray relational analysis (GRA) (Mattila & Virtanen, 2014), genetic algorithms (Saranga & Kumar, 2006), and Taguchi (Esangbedo et al., 2024) methods. These methods are the techniques for achieving goals such as quality improvements, cost management, and efficiency increase. GRA can be more effective in multi-criteria decision-making (MADM) problems and reduces the alternatives and their performance attributes to a single value, providing an advantage in the optimization of multiple goals (Esangbedo et al., 2024; Mattila et al., 2014). Machine learning is a powerful tool used in classification, prediction, and optimization problems in data analysis where the number of experiments and samples is high, especially when there is a correlation between the experimental results (Jaafaru & Agbelie, 2022; Karaoğlu et al., 2022). Genetic algorithms can be a suitable solution for especially complex design and optimization problems. Inspired by the evolutionary processes of the universe, genetic algorithms suggest a large number of possible solutions in the design area and continuously improve them (Saranga & Kumar, 2006; Yang & Yang, 2012). The Taguchi method provides significant advantages, especially in quality improvement, variation control, and robust design. Compared to other methods, it enables obtaining more information with fewer experiments and producing more stable and high-quality products. However, it may have some limitations in more complex cases, such as multi-objective optimization; however, it is a very effective method in single-target improvement processes. Therefore, the Taguchi method is the most accurate one for estimating multiple variations with a small number of experiments, such as man-sat optimization in aircraft maintenance (Eltoukhy et al., 2020; Esangbedo et al., 2024; Zhang et al., 2024).

One of the most effective methodologies for achieving optimization in maintenance is the Taguchi method, a robust statistical tool designed to improve process efficiency (van der Weide et al., 2022; Shandookh et al., 2024). The Taguchi method employs an orthogonal array design to systematically evaluate the impact of various factors on maintenance outcomes (Sukthomya & Tannock, 2005; Azadeh et al., 2016). This approach identifies optimal conditions that minimize costs and maximize efficiency by analyzing key variables such as task intervals, labor distribution, and fleet size (Azadeh et al., 2016; Zhang et al., 2024). Its application in aviation maintenance not only ensures compliance with stringent safety requirements but also supports data-driven decision-making to streamline operations (Zio et al., 2019).

The benefits of optimization extend beyond cost savings (Duvignau et al., 2021). Enhanced maintenance processes lead to improved fleet availability, reduced downtime, and increased operational capacity (Şentürk et al., 2010; Regattieri et al., 2015). For instance, extending the intervals between maintenance tasks can significantly reduce the frequency of checks, translating into fewer disruptions to flight schedules (Shaukat et al., 2020; Al-Thani et al., 2016). Additionally, redistributing tasks across different maintenance checks ensures a balanced workload, preventing bottlenecks and maintaining service quality (Zhang et al., 2024; Regattieri et al., 2015; Shaukat et al., 2020; Al-Thani et al., 2016).

The labor-intensive nature of aviation maintenance means that man-hour costs form a substantial part of an airline's operational expenses (Beliën et al., 2012; Martone et al., 2024). In major maintenance hubs, man-hour costs range from $80 to $120, depending on the workforce's skill level and region. In the fleet of Boeing 777s, optimizing the allocation of man-hours and reducing the number of A-checks generate substantial cost savings without compromising safety or performance.

The current system generates 60 days of downtime annually across the fleet, directly impacting operational revenue. The potential benefits of extending the A-check interval are significant. For a 12-aircraft fleet, this optimization reduces annual man-hours by 5196, saves $416.000 in labor costs, and generates an additional $1 million in operational revenue through increased fleet availability. These findings highlight the critical role of strategic maintenance planning in achieving cost efficiency and operational excellence in the aviation sector.

This paper aims to contribute to the growing literature on aviation maintenance optimization by presenting a case study on the extension of the Boeing 777 A-check interval. The Taguchi method was optimized for the Boeing 777 fleets consisting of 12 and 24 aircraft for the L-check maintenance cards to be performed at 1000 FH and 1500 FH A-check maintenance intervals using the signal-to-noise (S/N) formulation. Thus, maintenance intervals were increased without compromising flight safety standards, the number of task cards was reduced, the aircraft ground time was reduced, maintenance expenses were reduced, and transmission revenues increased as the aircraft were kept in flight for longer periods. This method provides efficiency, cost reduction, and improved aircraft availability. The findings demonstrate the applicability of this approach and provide a roadmap for similar applications across other aircraft types and fleets. Besides, this study highlights the transformative potential of innovative maintenance strategies in modern aviation by integrating regulatory compliance, operational efficiency, and cost-effectiveness. The rest of the study was organized as follows: Section 2 explains the proposed approach. In Section 3, the experimental results of the proposed approach are given and discussed. Finally, Section 4 summarizes the conclusions of the study.

2. METHODS

2.1. Current A-Check Interval (1000 FH)

Conducted approximately every 74 days based on a daily utilization rate of 13,5 FH. Each check requires a one-day downtime with three shifts. Each aircraft undergoes five A-checks annually, totaling 60 checks across the 12 aircraft fleet. This results in 60 days of annual downtime for the fleet.

2.2. Proposed A-Check Interval (1500 FH)

Aircraft manufacturers such as Boeing prepare a maintenance planning document (MPD) that includes mandatory basic maintenance when producing aircraft. Then, airlines that have the relevant aircraft in their fleet prepare a customized maintenance planning document (CMPD). Airline maintenance is specific to their aircraft and is carried out by the CMPD. For this study, conducted every 111 days, maintaining the same one-day check duration. Annual A-checks per aircraft drop to 3,3, reducing the fleet-wide total to 40 checks. This reduces downtime to 40 days annually, recovering

20 operational days for the fleet. The man-hour graph according to cards' reference intervals before applying the technique proposed in this study is shown in Figure 1.

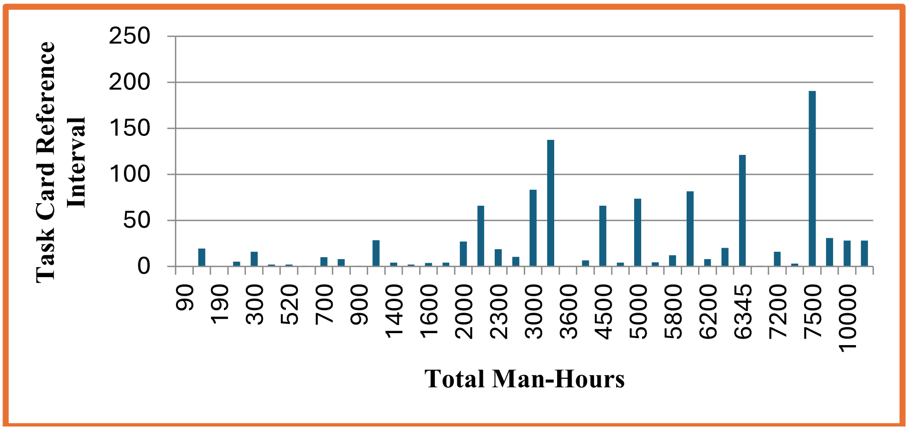

Figure 2. Distribution Chart of Maintenance Cards According to Reference Intervals

2.3. Optimization Methodology

Task data from Boeing's maintenance manuals and airline-specific records were analyzed to identify tasks with intervals of over 1000 FH. These tasks were consolidated into a single 1500 FH A-check. The optimization is calculated as follows:

$$\text{Savings (Man Hours)} = (\text{Current Interval Hours} - \text{Proposed Interval Hours}) \times \text{Tasks/Hour} \quad (1)$$

For each task, man-hour savings were projected based on rescheduled intervals. Tasks deemed critical to safety or operations were excluded from rescheduling. Regulatory guidelines (Federal Aviation Administration, European Union Aviation Safety Agency) and manufacturer recommendations were strictly followed. Intermediate cleaning tasks were introduced every 500 FH to maintain cabin standards. Comprehensive cleaning remained at the proposed 1500 FH interval. The distribution chart of maintenance cards according to reference intervals is shown in Figure 2. A flowchart showing the proposed approach step by step and making it easy to follow is given in Figure 3.

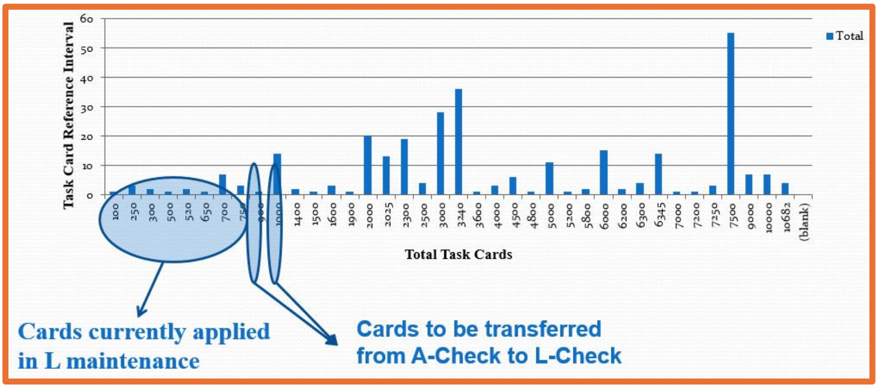

Figure 2. Distribution Chart of Maintenance Cards According to Reference Intervals

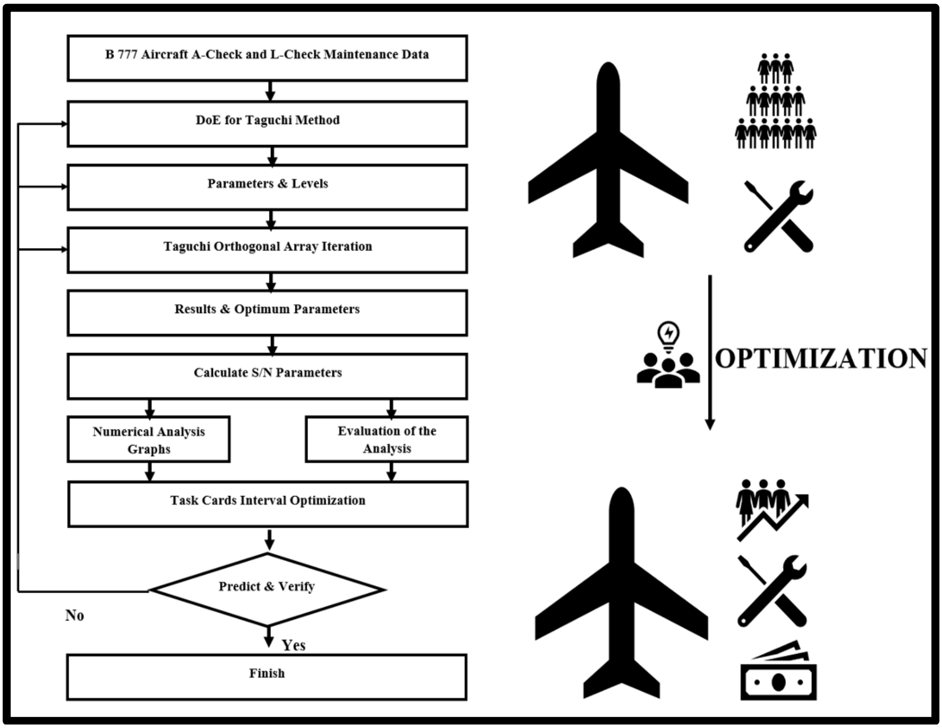

Figure 3. Boeing 777 Aircraft Optimization Flowchart

2.4. Taguchi Model for Man-Hour Optimization

The Taguchi method relies on designing experiments (Design of Experiments-DoE) to analyze the impact of different factors and determine optimal conditions. For this study, the following factors and levels were identified:

- I: A-check interval (1000 FH and 1500 FH).
- T: Task distribution (standard and optimized).
- H_{task}: Average man-hours per task card (standard and reduced).
- F: Fleet size (e.g., 12, 24 aircraft).
- Two levels are selected for each factor (e.g., A-check interval: 1000 FH and 1500 FH).
- An L_8 orthogonal array (Table 1) is suitable for this analysis, as it evaluates four factors at two levels each. This design ensures a balanced and efficient experimental structure.

Table 1. L_8 Orthogonal Array

Experiment	I (A-Check Interval)	T (Task Distribution)	H_{task} (Task Time)	F (Fleet Size)
1	1000 FH	Standard	2 hours	12 aircraft
2	1000 FH	Optimized	1.5 hours	24 aircraft
3	1500 FH	Standard	2 hours	24 aircraft
4	1500 FH	Optimized	1.5 hours	12 aircraft
5	1000 FH	Optimized	2 hours	24 aircraft
6	1000 FH	Standard	1.5 hours	12 aircraft
7	1500 FH	Optimized	2 hours	12 aircraft
8	1500 FH	Standard	1.5 hours	24 aircraft

The Taguchi method uses the S/N ratio to identify optimal conditions. For this study, the "smaller-is-better" criterion is applied, calculated as:

$$\frac{S}{N} = -10x \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (2)$$

where y_i represents the observed response values in each experimental run and n denotes the number of observations or repetitions conducted under the same experimental conditions. In this study, these responses correspond to man-hour savings ($MH_{savings}$) and cost savings ($C_{savings}$) measured across different experimental trials.

Each response value was obtained through controlled experimental trials, ensuring accuracy in evaluating maintenance efficiency improvements. The calculated S/N ratios according to y_i and n values in Table 2 provide insights into the optimal parameter settings that minimize variability while maximizing performance gains. Using the formulas in the given Equations 1-4, the S/N values in Table 2 were solved in the Wolfram Mathematica program. Further discussion on interpreting these results and their impact on maintenance optimization is provided in subsequent sections.

Table 2. Calculated S/N Values

Experiment No.	y_1	y_2	y_3	y_4	y_5	n	S/N Ratio
1	145	150	148	152	149	5	-43,25
2	138	140	142	141	139	5	-42,88
3	155	160	158	162	159	5	-44,05
4	132	135	134	137	136	5	-41.92
5	165	168	170	166	169	5	-44,85
6	140	144	142	146	143	5	-42,98
7	150	152	154	151	153	5	-43,75

For each experiment, $MH_{savings}$ and $C_{savings}$ are calculated using the following formulas:

$$MH_{savings} = \left(\frac{1}{I_{current}} - \frac{1}{I_{proposed}}\right) x\ T\ x\ H_{task}\ x\ F \tag{3}$$

where T is defined as either "standard" or "optimized". However, in Equation 3, T is multiplied by H_{task} indicating that T should be numerical rather than categorical. $T_{Standard}$ is 1, and $T_{Optimized}$ is 0,75. These values indicate that the optimized task distribution reduces workload efficiency by 25%, leading to lower required man-hours per task.

$$C_{savings} = MH_{savings}\ x\ C_{MH} \tag{4}$$

The final parameter selection was based on a combination of cost efficiency, operational feasibility, and regulatory compliance. While maximizing cost savings was a key objective, safety, workload balance, and adherence to aviation authorities' regulations were critical constraints. The final selection criteria included maximizing fleet availability while ensuring minimal maintenance disruptions, reducing total labor costs without overloading any maintenance interval, maintaining regulatory and manufacturer compliance for operational safety, and demonstrating a significant return on investment through tangible cost savings.

2.5. Experiment Design and Parameter Selection

The Taguchi method uses the orthogonal array approach to optimize processes with minimal experimental work while capturing significant variability. In this study, an L8 orthogonal array was initially considered, allowing multiple factors to be evaluated at two levels each. However, since 7 aircraft were taken to A-check maintenance during the calendar period in which the Boeing 777 A-check optimization study was conducted, only 7 aircraft could be tested.

The selection of 7 experiments was determined by the need to analyze key factors such as A-check intervals, task distribution strategies, fleet size changes, and man-hour savings. More experiments could have been conducted, but simply taking the experimental aircraft from flight to maintenance before the A-check maintenance service would both reduce operating revenues and increase maintenance costs. The use of a structured orthogonal array allowed meaningful results to be obtained with a limited number of trials, consistent with industry best practices for experimental optimization.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The conducted experiments provide useful insights into which factor combinations yield optimal savings while maintaining safety and regulatory compliance. The Taguchi method helps determine how changes in these factors impact total maintenance efficiency. The key takeaway is identifying an optimal balance where extending the A-check interval does not compromise safety but instead enhances fleet availability while reducing labor and cost expenditures.

Annual man-hours for A-checks decreased from 1586 to 1153 per aircraft, resulting in a fleet-wide savings of 5196 man-hours annually. Task redistribution eased workload during L-checks, with minor operational checks (e.g., General Visual Inspection tasks) added to L-checks without affecting TAT. The distributions of man hours according to the maintenance interval for A-check 1000 FH and A-check 1500 FH are shown in Figures 4 and 5, respectively. The man-hour graph in case of equalization of maintenance is demonstrated in Figure 6. Making 1000 FH reference cards in L0004 (In addition to the current situation) is shown in Figure 7. Lastly, the man-hour graph in case of equalization of maintenance is demonstrated in Figure 8.

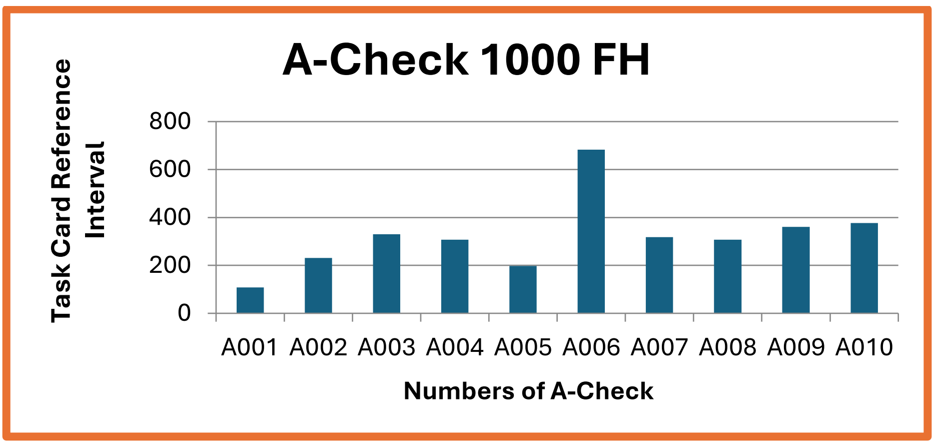

Figure 4. Distribution of Man Hours According to Maintenance Interval (1000 FH)

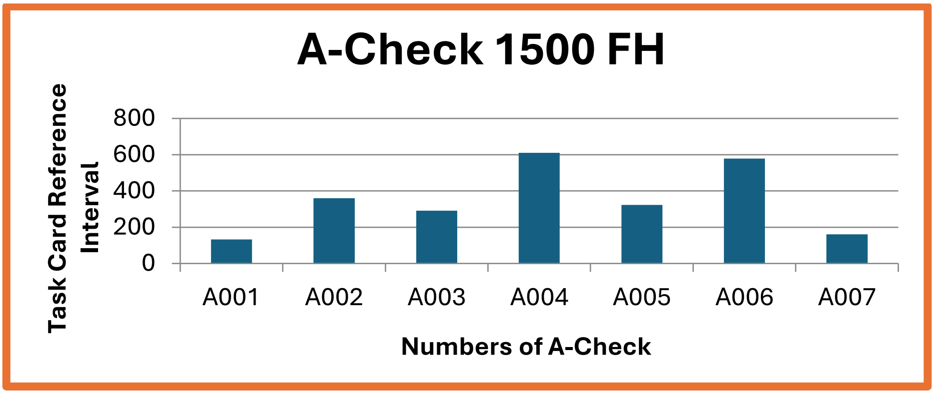

Figure 5. Distribution of Man Hours According to Maintenance Interval (1500 FH)

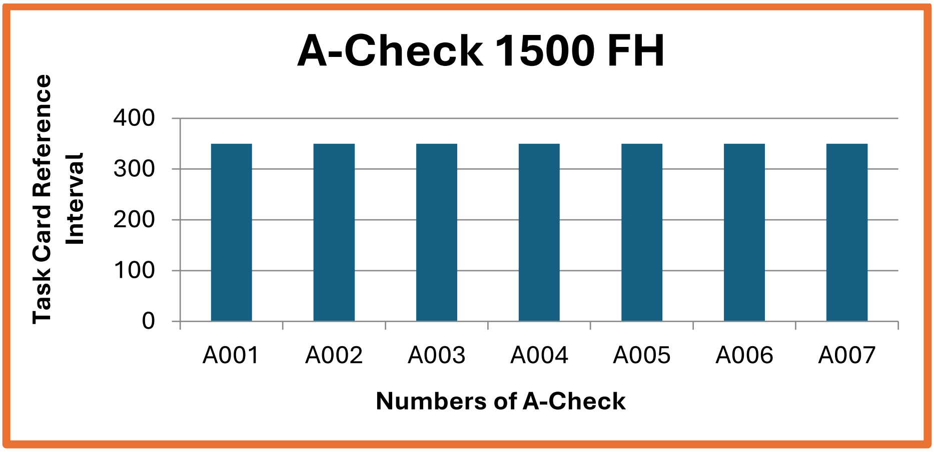

Figure 6. Man-Hour Graph in Case of Equalization of a Maintenance

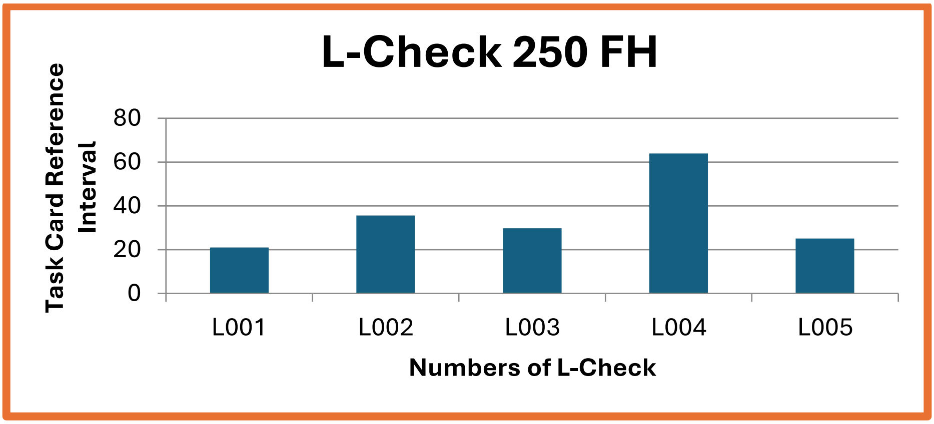

Figure 7. Making 1000 FH Reference Cards in L0004 (Addition to Current Situation)

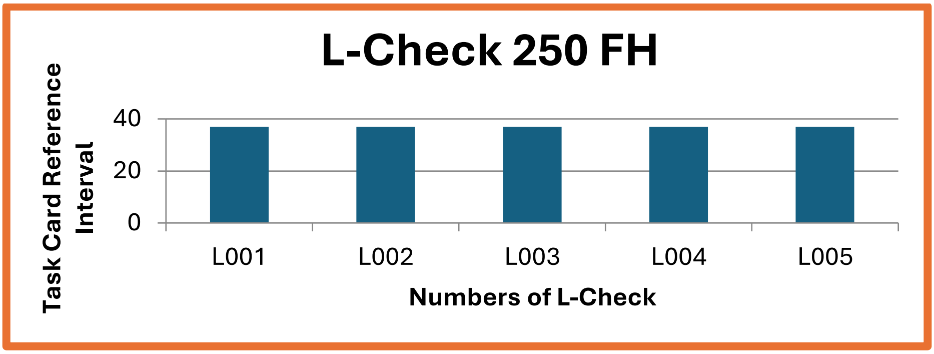

Figure 8. Man-Hour Graph in Case of Equalization of a Maintenance

The downtime was reduced from 60 to 40 days per year, providing 20 additional operational days for the fleet. Increased fleet availability generated $1 million in additional operational revenue per year. Annual labor cost savings of $416.000 based on an average man-hour cost of $80. Financial benefits of $1.416 million per year (including operational revenue and labor cost savings). Slot availability improved for other fleet maintenance. Workload was balanced during A- and L-checks without compromising safety.

The experiments conducted using the Taguchi method systematically evaluated the impact of differ-ent parameter combinations, including A-check interval (1000 FH vs. 1500 FH), task distribution (standard vs. optimized), man-hours per task card (standard vs. reduced), and fleet size (12 vs. 24 aircraft). Pre- and post-optimization results are given in Table 3. The experimental results demon-strated that the optimal scenario—extending A-checks to 1500 FH while balancing workload be-tween A- and L-checks—achieved maximum efficiency gains. The redistribution of tasks ensured that minor operational checks (such as general visual inspections) were added to L-checks without affecting turnaround time.

Table 3. Pre- and Post-Optimization Results

Parameter	Before Optimization (1000 FH)	After Optimization (1500 FH)
Annual A-Checks per Aircraft	5	3,3
Annual Fleet-Wide A-Checks	60	40
Annual Downtime (Days)	60	40
Man-Hours per Aircraft	1586	1153
Total Fleet-Wide Man-Hours Saved	-	5196
Annual Cost Savings ($)	-	416.000
Additional Operational Revenue ($)	-	1.000.000

4. CONCLUSION

Extending the A-check interval for Boeing 777 aircraft from 1000 FH to 1500 FH significantly reduced maintenance costs, increased operational efficiency, and improved fleet availability. The study highlights the importance of methodical task reassignment and integration of intermediate checks to maintain service standards. These findings highlight the importance of ongoing optimization in aviation maintenance, suggesting potential for broader application across aircraft types and maintenance strategies.

Future research can explore the integration of predictive maintenance techniques, leveraging machine learning and data analytics to enhance decision-making in maintenance scheduling. Additionally, further studies can examine the long-term effects of extended maintenance intervals on aircraft reliability and component lifespan. The applicability of this optimization framework to other aircraft models and operational environments can also be investigated, ensuring a more comprehensive understanding of its benefits and limitations. Collaborations between airlines, regulatory bodies, and maintenance providers can facilitate the development of adaptive maintenance schedules tailored to specific fleet requirements. These advancements can contribute to the evolution of more efficient, cost-effective, and data-driven maintenance strategies in the aviation industry.

Authors' Contribution
The authors confirm that they equally contributed to this paper.

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Conflict of Interest
The authors declare that there is no conflict of interest.

Statement of Research and Publication Ethics
Research and publication ethics were observed in the study.

REFERENCES

Ab-Samat, H., & Kamaruddin, S. (2014). Opportunistic maintenance (OM) as a new advancement in maintenance approaches: A review. *Journal of Quality in Maintenance Engineering*, *20*(2), 98-121.

Ahmadi, A., Söderholm, P., & Kumar, U. (2010). On aircraft scheduled maintenance program development. *Journal of Quality in Maintenance Engineering*, *16*(3), 229-255.

Al-Thani, N. A., Ahmed, M. B., & Haouari, M. (2016). A model and optimization-based heuristic for the operational aircraft maintenance routing problem. *Transportation Research Part C: Emerging Technologies*, *72*, 29-44.

Albakkoush, S., Pagone, E., & Salonitis, K. (2021). An approach to airline MRO operators planning and scheduling during aircraft line maintenance checks using discrete event simulation. *Procedia Manufacturing*, *54*, 160-165.

Azadeh, A., Gharibdousti, M. S., Firoozi, M., Baseri, M., Alishahi, M., & Salehi, V. (2016). Selection of optimum maintenance policy using an integrated multi-criteria Taguchi modeling approach by considering resilience engineering. *The International Journal of Advanced Manufacturing Technology*, *84*, 1067-1079.

Baptista, M., de Medeiros, I. P., Malere, J. P., Nascimento Jr, C., Prendinger, H., & Henriques, E. M. (2017). Comparative case study of life usage and data-driven prognostics techniques using aircraft fault messages. *Computers in Industry*, *86*, 1-14.

Beliën, J., Cardoen, B., & Demeulemeester, E. (2012). Improving workforce scheduling of aircraft line maintenance at Sabena Technics. *Interfaces*, *42*(4), 352-364.

Boeing. (2008). 777 family maintenance analysis & budget. *Aircraft Commerce*, *60*, 12-23.

Boeing. (2013). Assessing the 777’s long-term base maintenance costs. *Aircraft Commerce*, *87*, 28-42.

Boeing. (2016). *Boeing 777-300ER Maintenance Interval*. https://www.boeing-me.com/en/products-and-services/zzbuckit/777

Boeing. (2022). *777-200/-300 Airplane Characteristics for Airport Planning*. https://www.boeing.com/content/dam/boeing/boeingdotcom/commercial/airports/acaps/777_2_2er_3.pdf

Bowers, M. R., Bichescu, B. C., Bryan, N., Polak, G. G., Gilbert, K., & Keene, D. (2022). The maintenance conversion scheduling problem: Models and insights. *Naval Research Logistics*, *69*(7), 1027-1044.

Broderick, S. (2020). *Emirates Customizes 777 Checks Using Own Data*. https://aviationweek.com/air-transport/emirates-customizes-777-checks-using-own-data

Deng, Q., Santos, B. F., & Curran, R. (2020). A practical dynamic programming based methodology for aircraft maintenance check scheduling optimization. *European Journal of Operational Research*, *281*(2), 256-273.

Deng, Q., Santos, B. F., & Verhagen, W. J. (2021). A novel decision support system for optimizing aircraft maintenance check schedule and task allocation. *Decision Support Systems*, *146*, 113545.

Duvignau, R., Heinisch, V., Göransson, L., Gulisano, V., & Papatriantafilou, M. (2021). Benefits of small-size communities for continuous cost-optimization in peer-to-peer energy sharing. *Applied Energy*, *301*, 117402.

Eltoukhy, A. E. E., Wang, Z. X., Chan, F. T. S., Chung, S. H., Ma, H. L., & Wang, X. P. (2020). Robust Aircraft Maintenance Routing Problem Using a Turn-Around Time Reduction Approach. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, *50*(12), 4919-4932.

Esangbedo, M. O., & Samuel, B. O. (2024). Application of machine learning and grey Taguchi technique for the development and optimization of a natural fiber hybrid reinforced polymer composite for aircraft body manufacture. *Oxford Open Materials Science*, *4*(1), itae004.

Fu, S., & Avdelidis, N. P. (2023). Prognostic and Health Management of Critical Aircraft Systems and Components: An Overview. *Sensors*, *23*(19), 8124.

Ghobbar, A. A. (2010). Aircraft Maintenance Engineering. *Encyclopedia of Aerospace Engineering, John Wiley & Sons, Ltd*, 1-13.

Jaafaru, H., & Agbelie, B. (2022). Bridge maintenance planning framework using machine learning, multi-attribute utility theory and evolutionary optimization models. *Automation in Construction*, *141*, 104460.

Kabashkin, I., Perekrestov, V., Tyncherov, T., Shoshin, L., & Susanin, V. (2024). Framework for Integration of Health Monitoring Systems in Life Cycle Management for Aviation Sustainability and Cost Efficiency. *Sustainability*, *16*(14), 6154.

Karaoğlu, U., Mbah, O., & Zeeshan, Q. (2023). Applications of machine learning in aircraft maintenance. *Journal of Engineering Management and Systems Engineering*, *2*(1), 76-95.

Korba, P., Šváb, P., Vereš, M., & Lukáč, J. (2023). Optimizing aviation maintenance through algorithmic approach of real-life data. *Applied Sciences*, *13*(6), 3824.

Kulkarni, A., Yadav, D. K., & Nikraz, H. (2017). Aircraft maintenance checks using critical chain project path. *Aircraft Engineering and Aerospace Technology*, *89*(6), 879-892.

Lin, Z. L., Huang, Y. S., & Fang, C. C. (2015). Non-periodic preventive maintenance with reliability thresholds for complex repairable systems. *Reliability Engineering & System Safety*, *136*, 145-156.

Martone, F., Zazzaro, G., Inverno, M., De Luca, S., Mainieri, F., & Romano, G. (2024). A Supporting Framework for Aircraft MRO Operations: Capacity Planning, Tasks Traceability and Disembarked Items Tracking. In *2024 34th Congress of the International Council of the Aeronautical Sciences (ICAS)* (pp. 1-19).

Mattila, V., & Virtanen, K. (2014). Maintenance scheduling of a fleet of fighter aircraft through multi-objective simulation-optimization. *Simulation*, 90(9), 1023-1040.

Mofokeng, T. J., & Marnewick, A. (2017, June). Factors contributing to delays regarding aircraft during A-check maintenance. In *2017 IEEE Technology & Engineering Management Conference (TEMSCON)* (pp. 185-190). IEEE.

Papakostas, N., Papachatzakis, P., Xanthakis, V., Mourtzis, D., & Chryssolouris, G. (2010). An approach to operational aircraft maintenance planning. *Decision Support Systems*, *48*(4), 604-612.

Pimapunsri, K., & Weeranant, D. (2018). Solving complexity and resource-constrained project scheduling problem in aircraft heavy maintenance. *International Journal of Applied Engineering Research*, *13*(11), 8998-9004.

Pop, G. I., Titu, A. M., & Pop, A. B. (2023). Enhancing Aerospace Industry Efficiency and Sustainability: Process Integration and Quality Management in the Context of Industry 4.0. *Sustainability*, *15*(23), 16206.

Rao, M. V., Chaitanya, M. S. R. K., & Vidhu, K. P. (2017). Aircraft servicing, maintenance, repair & overhaul–the changed scenarios through outsourcing. *International Journal of Research in Engineering and Applied Sciences*, *7*(5), 249-270.

Regattieri, A., Giazzi, A., Gamberi, M., & Gamberini, R. (2015). An innovative method to optimize the maintenance policies in an aircraft: General framework and case study. *Journal of air transport management*, *44*, 8-20.

Saranga, H., & Kumar, U. D. (2006). Optimization of aircraft maintenance/support infrastructure using genetic algorithms—level of repair analysis. *Annals of Operations Research*, *143*, 91-106.

Sarhani, M., Ezzinbi, O., El Afia, A., & Benadada, Y. (2016, May). Particle swarm optimization with a mutation operator for solving the preventive aircraft maintenance routing problem. In *2016 3rd International Conference on Logistics Operations Management (GOL)* (pp. 1-6). IEEE.

Shandookh, A. A., Ogaili, A. A. F., & Al-Haddad, L. A. (2024). Failure analysis in predictive maintenance: Belt drive diagnostics with expert systems and Taguchi method for unconventional vibration features. *Heliyon*, *10*(13), e34202.

Shaukat, S., Katscher, M., Wu, C. L., Delgado, F., & Larrain, H. (2020). Aircraft line maintenance scheduling and optimisation. *Journal of Air Transport Management*, *89*, 101914.

Sriram, C., & Haghani, A. (2003). An optimization model for aircraft maintenance scheduling and re-assignment. *Transportation Research Part A: Policy and Practice*, *37*(1), 29-48.

Sukthomya, W., & Tannock, J. D. (2005). Taguchi experimental design for manufacturing process optimisation using historical data and a neural network process model. *International Journal of Quality & Reliability Management*, *22*(5), 485-502.

Şentürk, C., Kavsaoğlu, M. S., & Nikbay, M. (2010, September). Optimization of aircraft utilization by reducing scheduled maintenance downtime. In *10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference* (p. 9143).

Tyagi, A., Tripathi, R., & Bouarfa, S. (2023). Learning from past in the aircraft maintenance industry: An empirical evaluation in the safety management framework. *Heliyon*, *9*(11), e21620.

van der Weide, T., Deng, Q., & Santos, B. F. (2022). Robust long-term aircraft heavy maintenance check scheduling optimization under uncertainty. *Computers & Operations Research*, *141*, 105667.

Verhagen, W. J., Santos, B. F., Freeman, F., van Kessel, P., Zarouchas, D., Loutas, T., ... & Heiets, I. (2023). Condition-Based Maintenance in Aviation: Challenges and Opportunities. *Aerospace*, *10*(9), 762.

Vieira, D. R., & Loures, P. L. (2016). Maintenance, repair and overhaul (MRO) fundamentals and strategies: An aeronautical industry overview. *International Journal of Computer Applications*, *135*(12), 21-29.

Yang, Z., & Yang, G. (2012). Optimization of Aircraft Maintenance plan based on Genetic Algorithm. *Physics Procedia*, *33*, 580-586.

Yilmaz, O., Gindy, N., & Gao, J. (2010). A repair and overhaul methodology for aeroengine components. *Robotics and Computer-Integrated Manufacturing*, *26*(2), 190-201.

Zhang, Q., Chung, S. H., Ma, H. L., & Sun, X. (2024). Robust aircraft maintenance routing with heterogenous aircraft maintenance tasks. *Transportation Research Part C: Emerging Technologies*, *160*, 104518.

Zio, E., Fan, M., Zeng, Z., & Kang, R. (2019). Application of reliability technologies in civil aviation: Lessons learnt and perspectives. *Chinese Journal of Aeronautics*, *32*(1), 143-158.