Investigation into Data Mining for Analysis and Optimization of Direct Maintenance Costs in Civil Aircraft Operations

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Abstract

The maintenance cost of civil aircraft plays a pivotal role in gauging both their maintainability and economic viability, constituting a substantial portion of overall operating expenses. With the burgeoning volume of aircraft operating data, data mining technology emerges as a powerful tool capable of extracting valuable insights. This research addresses the challenge of the limited availability of actual aircraft maintenance data during the developmental phase of civil aircraft. The study delves into the analysis and optimization of direct maintenance costs for civil aircraft through the application of data mining techniques. The investigation encompasses an exploration of the theoretical underpinnings of direct maintenance cost analysis using data mining, a comprehensive analysis of factors influencing the direct maintenance cost derived from data mining, and the establishment of a Direct Maintenance Cost (DMC) analysis method. Building upon this foundation, a model for the direct maintenance cost analysis of civil aircraft is formulated and fine-tuned to achieve the objective of cost reduction. The outcomes of this research hold significant implications for diminishing aircraft life cycle expenses, thereby enhancing the competitiveness of aircraft in the market.

Keywords: Data Mining, Civil Aircraft, Direct Maintenance Cost

1. Introduction

The realm of civil aircraft maintenance cost is multifaceted, encompassing both direct maintenance cost (DMC) and indirect maintenance cost. DMC, constituting the direct expenditures on man-hours and materials involved in maintenance processes, includes airframe and power plant maintenance costs. Notably, these individual components can further incorporate labor and material costs, respectively [1]. The intricate nature of DMC underscores its intrinsic connection with the developmental stage and maintenance design capabilities of aircraft, making it a pivotal facet of the direct operating cost and a crucial parameter for evaluating the maintainability and economic viability of civil aircraft [2].

Given its significant impact on airline profits, the magnitude of DMC directly influences the decision-making process for aircraft acquisition by airline companies, with an aversion to excessively high DMC values. Consequently, understanding and analyzing DMC require a wealth of maintenance data generated during aircraft operation. However, the current state of affairs reveals a scarcity of systematically managed data, posing challenges to the timely, accurate, and collaborative analysis of DMC in civil aircraft [4-9].

To address this critical gap, this research aims to delve into the application of data mining technology for DMC analysis. The utilization of historical maintenance data, coupled with advanced data mining methods, will enable the extraction of valuable insights and knowledge. This approach seeks to autonomously, intelligently, and expeditiously uncover

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latent dependencies within extensive maintenance datasets, ultimately presenting optimization suggestions for DMC from diverse perspectives. This paper advocates for the integration of data mining techniques as a strategic means to extract pertinent information from historical maintenance data, laying the groundwork for future advancements in DMC optimization. Through this initiative, we aspire to enhance the efficiency, accuracy, and collaborative aspects of civil aircraft DMC analysis, fostering a more informed and economical approach to maintenance practices in the aviation industry.

2. Literature Review

2.1. Direct Maintenance Cost (DMC) and Its Significance

The direct maintenance cost (DMC) of civil aircraft is a pivotal factor in the aviation industry, encompassing the direct expenses associated with man-hours and materials involved in maintenance processes. Previous studies highlight that DMC plays a crucial role in determining the economic viability and maintainability of civil aircraft [1]. Specifically, DMC is recognized as a key component of the direct operating cost, directly impacting the profit margins of airline companies [2]. Airlines are often reluctant to invest in aircraft with exorbitant DMC values, making it imperative to scrutinize and optimize these costs.

2.2. Link Between DMC and Aircraft Development

Scholars have extensively explored the intricate relationship between DMC and the developmental level of aircraft. Research indicates that DMC is closely tied to the maintenance design capabilities of aircraft [2]. The design aspects of an aircraft directly influence the magnitude of DMC, making it an essential parameter for evaluating the efficiency and economy of civil aircraft [2]. Understanding and managing this link is crucial for airlines to make informed decisions about aircraft acquisition, considering the long-term implications on operating costs.

2.3. Importance of Maintenance Data in DMC Analysis:

The process of DMC analysis relies heavily on the availability and quality of maintenance data generated during aircraft operations. Previous studies emphasize that a large volume of maintenance data is necessary for a comprehensive DMC analysis [3]. However, challenges arise from the current scarcity of systematically managed data, impacting the timeliness, accuracy, and collaborative nature of DMC analysis in civil aircraft [4-9]. Addressing these challenges is essential for improving the overall effectiveness of maintenance cost analysis.

2.4. The Role of Data Mining in DMC Analysis

Recognizing the limitations in the current state of maintenance data management, recent literature advocates for the integration of data mining technology in DMC analysis [4-9]. Data mining methods are proposed as a means to extract valuable information and knowledge from historical maintenance data automatically, intelligently, and quickly. The aim is to uncover hidden dependencies within the data and provide optimization suggestions for DMC from various perspectives. This approach is positioned as a strategic solution to enhance the efficiency and accuracy of civil aircraft DMC analysis.

2.5. Research Gap and the Need for DMC Optimization

The literature underscores the existing research gap in terms of scarce and unmanaged maintenance data [4-9]. This gap poses a significant challenge to the advancement of timely and accurate DMC analysis. The proposed research seeks to address this gap by leveraging data mining techniques to extract useful information from historical maintenance data. Through this initiative, the groundwork for DMC optimization is laid, aiming to contribute to the development of more informed and economical maintenance practices in the aviation industry.

3. Methodology

Aircraft DMC (Direct Maintenance Cost) analysis is a critical aspect of the aviation industry, relying on the meticulous examination of maintenance data gathered over years by airline companies. The prevailing global calculation methods, notably the ATA (Air Transport Association), AEA (Association of European Airlines), and NASA 95 method, form

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the cornerstone of this analysis. These methodologies serve as indispensable tools for airlines to gauge and manage the direct maintenance costs associated with their fleets [10].

However, the significance of DMC analysis extends beyond mere number crunching. When delving into the intricacies of civil aircraft maintenance, a harmonious integration with aircraft design, marketing, and customer service activities becomes imperative [11]. This synchronization ensures that DMC analysis is not treated in isolation but is seamlessly interwoven into the broader spectrum of aviation operations.

Effectively conducting DMC analysis demands a strategic and comprehensive approach, necessitating careful planning and coordination at each stage. It is not merely a financial exercise but a holistic process that influences and is influenced by various facets of the aviation industry [12]. From the initial stages of aircraft design to the subsequent marketing endeavors and ongoing customer service commitments, DMC analysis plays a pivotal role in shaping decisions and strategies.

Figure 1 illustrates the primary stages of the direct maintenance cost analysis process, serving as a visual guide to the multifaceted nature of this endeavor. Recognizing the interconnectedness of DMC analysis with other crucial aspects of aviation underscores the need for a well-coordinated and synchronized approach, ensuring that the insights derived from maintenance data contribute meaningfully to the overall efficiency and sustainability of civil aviation. As the aviation landscape continues to evolve, refining and adapting these analysis methods remains integral to fostering a robust and cost-effective industry.

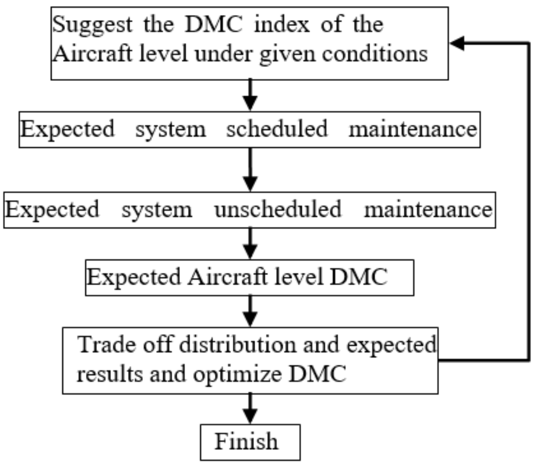

Figure 1. DMC analysis process

The analysis of aircraft-level DMC (Deferred Maintenance Cost) is a comprehensive process that focuses on individual components. The maintenance activities for an aircraft can be broadly categorized into two main types: planned maintenance tasks and unplanned maintenance tasks. Within these categories, a further breakdown reveals a more detailed classification. Planned maintenance tasks can be sub-divided into system scheduled maintenance tasks, which involve pre-determined periodic inspections and upkeep activities to ensure the smooth functioning of various systems, and structural maintenance tasks, which encompass the maintenance activities related to the aircraft's structural integrity. On the other hand, unplanned maintenance tasks are characterized by unexpected issues or malfunctions that require immediate attention [13]. They are further divided into system unscheduled maintenance tasks, addressing unforeseen system failures, and structural maintenance tasks, dealing with unexpected structural issues. This meticulous categorization facilitates a systematic approach to aircraft maintenance, enabling efficient planning and execution of maintenance activities to ensure the optimal performance and safety of the aircraft.

3.1. System Scheduled Maintenance Tasks DMC Analysis

The scheduled maintenance of an aircraft encompasses various crucial aspects, encompassing line scheduled maintenance, scheduled checks, and shop maintenance tasks. To effectively manage and execute these maintenance activities, the Aircraft Maintenance Planning Document plays a pivotal role by providing a comprehensive list of scheduled maintenance tasks for the various systems, onboard equipment, and components of the aircraft. This encompasses tasks such as scheduled updates, routine checks, and necessary service work. The detailed breakdown of these scheduled maintenance tasks is systematically presented in Table 1, offering a structured overview of the responsibilities involved in maintaining the aircraft's optimal performance and safety standards. This document serves as a critical reference point for aviation professionals, ensuring that the aircraft undergoes timely and thorough maintenance, contributing to its overall reliability and longevity.

The DMC of the Scheduled Check is shown in formula 1.

$$DMC_{Scheduled} = \frac{R \times MH_{ON}}{T_R} \quad (1)$$

In the equation:

$DMC_{Scheduled}$ - Scheduled maintain DMC ($/fh).

R- Maintenance man hour rate ($/h).

MH_{ON} - In-situ maintenance man hour for scheduled maintenance tasks (h).

T_R - Maintenance interval for scheduled maintenance tasks (fh).

In the realm of aerospace engineering and maintenance, the determination of the DMC (Direct Maintenance Cost) assumes a pivotal role, particularly when addressing the scheduled maintenance of life limit components. This intricate calculation is elucidated through Formula 2, which serves as a fundamental tool in the meticulous planning and execution of maintenance procedures. As life limit components are crucial for ensuring the longevity and optimal performance of aircraft and related systems, the DMC calculation becomes indispensable in forecasting and managing the costs associated with their maintenance. This research delves into the nuances of Formula 2, seeking to unravel its underlying principles and implications within the broader context of aviation maintenance practices. Through a comprehensive exploration of this calculation method, the study aims to contribute valuable insights to the field, enhancing our understanding of how scheduled maintenance can be strategically approached for life limit components, ultimately influencing cost-effectiveness and operational efficiency in the aerospace industry.

$$DMC_{Scheduled} = \frac{R \times MH_{ON_{lim}} + MC}{T_R} \quad (2)$$

In the equation:

MH_{ON_lim} - The off-site maintenance man hours of the scheduled maintenance tasks of the life limit components (h).

MC - Maintenance material costs for scheduled maintenance tasks.

Table 1. Scheduled maintenance task classification

Type	Name	Definition
Scheduled update	DIS	Discard is defined as when an equipment reaches the life limit, whether it has a failure or not, it will be discarded and replaced with a new one.
	RST	Restoration is defined as both of the labor cost and material cost of replacement and cleaning component, repair and overhauled the equipment.
Scheduled Check	GVI	General Visual Inspection is to check for obvious damage, failure and abnormal signs, while conduction a visual inspection of the internal/ external installation components. Except the special instructions, GVI should be within the reachable range.
	OPC	Operational Check is a work to find the failure, which doesn’t need quantitative requirements.
	FNC	Function Check is defined as a qualitative check, which is used to ensure whether a function or multiple function within the specification range or not.

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	DET	Visual Check is defined as an observation work to find the failure, which doesn't need quantitative requirements.
	SDI	In order to inspect the damage, failure or abnormal sign, detailed inspection is defined as a careful examination of a special project and component.
Service	LUB	In order to maintain the inherent design performance to take a lubrication task.

3.2. System Unscheduled Maintenance Tasks DMC Analysis

Unscheduled maintenance is a critical aspect of overall maintenance management, with its key determinants being the mean time between unscheduled removals and the no-fault-found rate. In essence, the effectiveness of addressing unscheduled maintenance concerns hinges on understanding and managing these factors [14][15]. Particularly, when dealing with consumable components, a unique set of challenges and considerations come into play. Consumable components, by nature, are those that are designed to be replaced directly following a failure. In such cases, the cost associated with unscheduled maintenance is encapsulated in both labor and material expenses, collectively referred to as Direct Maintenance Cost (DMC). The computation of DMC for unscheduled maintenance involving consumable components is a crucial step in evaluating the economic implications of these maintenance activities. This calculation involves a meticulous assessment of the labor and material costs incurred, providing valuable insights into the financial impact of addressing unscheduled maintenance events associated with consumable components. As organizations strive to optimize maintenance strategies and resource allocation, a thorough understanding of DMC for unscheduled maintenance proves instrumental in making informed decisions for efficient and cost-effective maintenance practices.

$$DMC_{Scheduled} = \frac{R\times 0.5+P_L}{MTBUR} \quad (3)$$

In the equation:

$DMC_{Unscheduled}$ - Unscheduled maintenance DMC ($/fh).

P_L - The purchase price of the component (including off-site labor costs).

MTBUR - mean time between unscheduled removals (fh).

The process of managing non-consumable components involves sending them for repair once they fail. Drawing upon engineering expertise, it has been observed that the maintenance cost incurred due to the absence of any fault in the component constitutes approximately 10% of the component's total cost. In contrast, the cost associated with regular repairs amounts to about 25% of the component's overall cost. In light of these considerations, the calculation of the Direct Maintenance Cost (DMC) for unscheduled maintenance of such components can be outlined as follows.

$$DMC_{Scheduled} = \frac{P_L\times(25\%-15\%NFFR)}{MTBUR} \quad (4)$$

In the equation:

NFFR - No fault found rate.

3.3. Structural Maintenance Tasks DMC Analysis

Structural maintenance DMC is divided into structural scheduled maintenance DMC and structural unscheduled maintenance DMC according to maintenance tasks. The scheduled maintenance cost of the structure comes from the scheduled maintenance tasks of the structure in the aircraft MPD, and the calculation formula is as follows.

$$DMC_{Structure\_Scheduled} = \frac{R\times\sum MH_{ON_i}+\sum MC_i}{T_R} \quad (5)$$

In the equation:

$DMC_{Structure\_scheduled}$ – Structure scheduled DMC ($/fh).

MH_{OHi} - The in-situ maintenance man hour required for the structural scheduled maintenance task i (h).

MC_i - The maintenance material cost required for the structural scheduled maintenance task i ($).

TR - The maintenance interval of the scheduled maintenance task of the structure (fh).

Research in the field of maintenance costs has consistently shown that the financial implications of structural unscheduled maintenance far exceed those associated with scheduled maintenance. This phenomenon is not arbitrary but follows a discernible pattern, as evidenced by statistical analyses. The relationship between these two types of maintenance costs is typically characterized by a multiple, highlighting the substantial financial burden incurred when addressing unforeseen structural issues. To quantify this relationship, a calculated approach is employed, providing a systematic method for estimating the costs associated with structural unscheduled maintenance in relation to its scheduled counterpart. Understanding and accurately predicting these costs is crucial for effective budgeting and resource allocation in industries where infrastructure integrity is paramount [16][17]. This research aims to delve deeper into the dynamics of structural maintenance costs, offering valuable insights into the factors influencing these financial patterns and contributing to the development of more informed and strategic maintenance planning strategies.

$$DMC_{Structure\_Unscheduled} = \beta \times DMC_{Structure\_Scheduled} \quad (6)$$

In the equation:

$DMC_{Structure\_Unscheduled}$ – Structure unscheduled DMC ($/fh).

β - According to the statistical data of structural maintenance, it is generally 1.5-2.5.

4. Resarch Results

4.1. Data Collection

The first step of DMC analysis based on data mining is to collect maintenance data during the use of aircraft. Then the data is preprocessed through the expert model, useful data is initially screened, data cleaning, data integration, data transformation are completed to form a database [10, 11]. According to the data needed in the DMC analysis, the aircraft maintenance data is divided into line maintenance, scheduled maintenance and unscheduled maintenance for collection.

The line maintenance data includes the type and date of the actual line maintenance work, the number of pre-flight/transit/post-flight inspections, the actual flight time and block time of the aircraft.

The scope of scheduled maintenance data is the scheduled maintenance content of the airline based on the main manufacturer of the civil aircraft in the maintenance plan documents, including A Check, multiple A Check, C Check, and multiple C Check. MPD task number, task interval, actual working hours, related components information and other data need to be recorded.

The scope of unscheduled maintenance data includes unscheduled maintenance work during the execution of scheduled maintenance tasks or during operation, including landing gear overhaul, APU overhaul, engine overhaul, and replacement of life limit components. The actual working hours, aviation material information, the time of use this time, the date of disassembly and assembly, and the repair cost of the maintenance task need to be collected.

4.2. Data Mining

In this research endeavor, a meticulous approach will be employed to choose algorithms that are well-suited for conducting thorough mining of aircraft maintenance data. Recognized data mining algorithms such as neural networks, support vector machines, K-means clustering, and association rule algorithms will be carefully selected to create models for generating association rules. Our focus will be on conducting extensive data mining specifically on the DMC (Data Monitoring and Collection) values and trends associated with each individual aircraft as well as entire fleets.

By delving into the intricacies of DMC values and trends, our objective is to identify sudden changes and abnormal patterns, thereby shedding light on potential issues affecting aircraft maintenance. Through the systematic analysis of a substantial volume of data, we aim to unearth the underlying causes of these variations. Furthermore, this research seeks to identify and comprehend the key factors influencing DMC values.

The utilization of advanced data mining techniques will provide a comprehensive understanding of the intricate relationships within the aircraft maintenance data. The findings of this research will not only contribute to a more profound comprehension of the factors influencing DMC but will also facilitate the development of robust models for predictive analysis, enhancing the efficiency and effectiveness of aircraft maintenance practices. This research endeavors to pave the way for more informed decision-making in the realm of aviation maintenance by harnessing the power of data mining algorithms to uncover hidden insights and patterns.

4.3. DMC Optimization Based on Data Mining

According to the results of data mining, the DMC design can be optimized to reduce DMC.

Choose maintenance intervals and maintenance tasks in reason. The rationality of the maintenance interval and the selection of maintenance tasks will directly affect the DMC. For maintenance tasks that affect safety, a reasonable maintenance interval needs to be recommended based on the failure rate data. For other maintenance tasks, the number of scheduled maintenance tasks should be minimized under the premise of ensuring safety.

Improve maintainability design and reduce maintenance man hour. For civil aircraft, the maintainability directly affects the maintenance hours of equipment or structures. Therefore, accessibility should be improved and modular design should be strengthened to reducing maintenance man hours.

Reduce failure rate to reduce unscheduled maintenance. Unscheduled maintenance account for a significant proportion of DMC. In the case of certain development costs and spare parts costs, equipment with high reliability should be selected as far as possible.

Reduce the price of aviation materials or spare parts. When selecting the equipment provided by the supplier, the main manufacturer should select materials or spare parts with favorable prices on the premise of ensuring that the functions and reliability meet the indicators to reduce the cost of unscheduled repairs.

5. Conclusion

The Aircraft Data Monitoring and Control (DMC) system plays a pivotal role in establishing a harmonious equilibrium among aircraft safety, reliability, and economic efficiency, ultimately leading to increased profitability for aircraft operators. This research delves into a comprehensive examination of the DMC analysis method for civil aircraft, aiming to enhance its performance through the application of data mining techniques. By leveraging the insights obtained through data mining, the paper advocates for DMC optimization, introducing innovative ideas to enhance its functionality. The primary objective is to align the DMC with stringent design index requirements, ensuring that it not only meets industry standards but also exceeds expectations. This strategic optimization approach is envisaged to pave the way for the successful integration of DMC into the market, thereby contributing significantly to the overall efficiency and success of civil aircraft operations. Through continuous refinement and adaptation, the proposed optimization ideas are poised to elevate the DMC system to new heights, facilitating a seamless blend of safety, reliability, and economic effectiveness for the benefit of aircraft operators in the competitive aviation landscape.

6. Declarations

6.1. Author Contributions

Conceptualization: Z.T. and Z.L.; Methodology: Z.L.; Software: Z.T.; Validation: Z.T. and Z.L.; Formal Analysis: Z.T. and Z.L.; Investigation: Y.L.; Resources: Y.L.; Data Curation: Y.L.; Writing Original Draft Preparation: Y.L. and Z.T.; Writing Review and Editing: Y.L. and Z.T.; Visualization: Z.T.; All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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6.4. Institutional Review Board Statement

Not applicable.

6.5. Informed Consent Statement

Not applicable.

6.6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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