

**ARTIFICIAL INTELLIGENCE APPLICATIONS SELECTION VIA MCDM
METHODS IN AVIATION MAINTENANCE, REPAIR & OVERHAUL
INDUSTRY**

(HAVACILIK BAKIM, ONARIM VE YENİLEME SEKTÖRÜNDE YAPAY ZEKA
UYGULAMALARININ ÇKKV YÖNTEMLERİ İLE SEÇİLMESİ)

by

Metin Emin ASLAN, B.Sc.

Thesis

Submitted in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

in

INDUSTRIAL ENGINEERING

in the

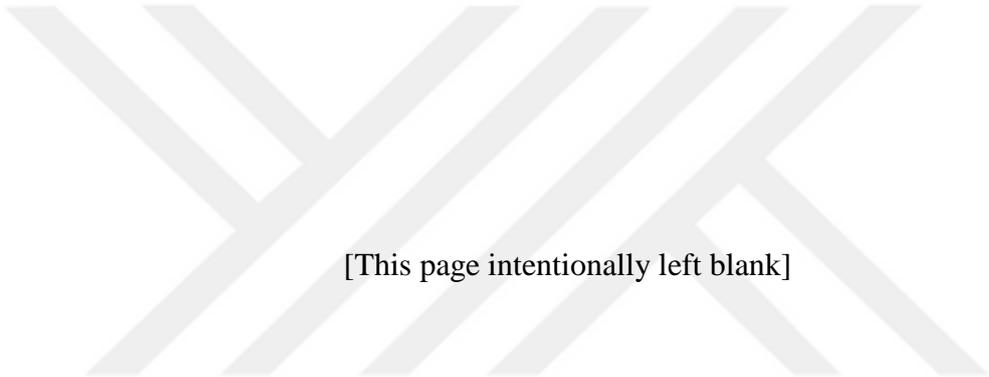
GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

of

GALATASARAY UNIVERSITY

Supervisor: Prof. A. Çağrı TOLGA

July 2022



[This page intentionally left blank]

ACKNOWLEDGEMENTS

I would like to go my deepest appreciation to my esteemed supervisor, Prof. A. Çađrı Tolga, for his marvelous supervision, kind support, invaluable guidance, very constructive feedback, and generous tolerance.

I would also like to express my endless gratitude to my parents and brothers who have provided unflagging support throughout my entire life.

And, I would also like to point out that this journey would not have been completed without my dear wife who always supported and encouraged me endlessly, thanks to her a lot.

July 2022

Metin Emin ASLAN

TABLE OF CONTENTS

LIST OF SYMBOLS	vi
LIST OF FIGURES	vii
LIST OF TABLES	viii
ABSTRACT.....	ix
ÖZET	xi
1. INTRODUCTION.....	1
2. LITERATURE REVIEW.....	3
3. ARTIFICIAL INTELLIGENCE TECHNOLOGY.....	10
3.1. Definition of Artificial Technology	10
3.2. Advantages and Disadvantages.....	12
3.3. Fields of Usage.....	13
4. MAINTENANCE, REPAIR AND OVERHAUL (MRO) in AVIATION INDUSTRY.....	15
4.1. Definition of MRO.....	15
4.2. MRO Units and Processes.....	16
4.2.1. Line Maintenance	16
4.2.2. Base Maintenance	17
4.2.3. Production Planning and Control.....	17
4.2.4. Quality Assurance and Control.....	17
4.2.5. Engineering - Authorization	18
4.2.6. Material Planning.....	18
4.2.7. Sales & Marketing	20
4.2.8. Purchasing and Logistic.....	20
4.2.9. Financial Affairs	20
4.2.10. Human Resources and Training	21

5. ARTIFICIAL INTELLIGENCE APPLICATIONS IN MRO	22
5.1. Document Management	22
5.2. Augmented Reality.....	23
5.3. Anomaly Detection	23
5.4. Recruitment.....	23
5.5. Supply Chain Optimization.....	24
5.6. Predictive & Preventive Maintenance.....	24
5.7. Maintenance Scheduling	24
5.8. Automated Quality Control.....	25
6. USING MULTI CRITERIA DECISION MAKING (MCDM) METHODS on WHICH AREAS to APPLY AI TECHNOLOGY APPLICATIONS in MRO.....	26
6.1. Defining Criteria for Selection of MRO Process to Use AI.....	27
6.2. Implementing of the AHP Method to Weight Criteria.....	30
6.2.1. AHP (Analytical Hierarchy Process) Method	31
6.2.2. Determination of Criteria Weights via AHP Method	33
6.3. Selection of the Application Area by Using WEDBA Method	35
6.3.1. WEDBA (Weighted Euclidean Distance Based Approach) Method.....	35
6.3.2. Implementation of WEDBA to Prioritize Usage of Fields.....	38
7. USING MCDM METHOD on WHICH AI TOOL to USE FOR PREDICTIVE & PREVENTIVE MAINTENANCE.....	41
7.1. Defining Criteria for Selection of AI Tool among Alternatives to Use in Predictive and Preventive Maintenance	42
7.2. Weighting Criteria via AHP Method	45
7.3. Implementing WEDBA to Prioritize Alternative AI Tools	47
8. DISCUSSIONS	51
9. CONCLUSION.....	53
REFERENCES.....	55
BIOGRAPHICAL SKETCH.....	60

LIST OF SYMBOLS

AI	: Artificial Intelligence
IoT	: Internet of Things
RFID	: Radio Frequency Identification
MRO	: Maintenance, Repair and Overhaul
MCDM	: Multiple-Criteria Decision-Making
AHP	: Analytical Hierarchy Process
WEDBA	: The Weighted Euclidean Distance Based Approach
IATA	: International Air Transport Association
FAA	: The Federal Aviation Administration
SHGM	: Sivil Havacılık Genel Müdürlüğü (Directorate General of Civil Aviation - Turkey)
OEM	: Original Equipment Manufacturer
FH	: Flight Hour
FC	: Flight Cycle
AD	: Airworthiness Directives
SB	: Service Bulletin
MEL	: Minimum Equipment List
EO	: Engineering Order
PPM	: Predictive and Preventive Maintenance

LIST OF FIGURES

Figure 3.1: The hierarchy and sub-fields of AI	11
Figure 6.1: Overview of the MCDM process	27



LIST OF TABLES

Table 2.1: Detailed references of literature review	7
Table 3.1: The sector and fields of usage of AI technology	13
Table 6.1: The criteria considered when determining the field of usage of AI tech.....	30
Table 6.2: Comparison scale (Saaty, 2004)	31
Table 6.3: Random Consistency Index (Saaty, 1980).....	33
Table 6.4: Binary Comparison Matrix	33
Table 6.5: Normalized Binary Comparison Matrix	34
Table 6.6: Criteria weights of process selection	35
Table 6.7: Decision Matrix	38
Table 6.8: The standardized decision matrix	38
Table 6.9: The results of WEDBA implementation.....	39
Table 7.1: Features of Alternatives	41
Table 7.2: Binary Comparison Matrix	45
Table 7.3: Normalized Binary Comparison Matrix	46
Table 7.4: Criteria weights of process selection	47
Table 7.5: Decision Matrix	48
Table 7.6: The standardized decision matrix	48
Table 7.7: The results of WEDBA implementation.....	49

ABSTRACT

The aviation sector is growing day by day and its influence in the field of transportation is remarkably increasing. As a natural consequence of this, the number of aircraft operating in this sector is also gradually increasing. In parallel with this circumstance, it becomes more complicated and more costly to carry out maintenance-repair-overhaul (MRO) activities in compliance with determined aviation standards, which are vital for airworthiness and flight safety. It is a serious operation for the operators to organize these activities determined by international authorities and original equipment manufacturers (OEMs) and to arrange maintenance schedules with allocating adequate resources.

Airline operators are looking for ways to improve flight performance and flight safety, and to minimize maintenance-repair costs and the number of unplanned breakdowns over time. It is exceedingly difficult to achieve optimal results in such a large system with hundreds of variable factors. However, technological developments facilitate the exchange of data between interrelated operational activities and make it meaningful by processing the big data that emerges as a result of the operations performed. In this sense, artificial intelligence and machine learning concepts have started to be a big supporter of the MRO companies, such as in predictive and preventive maintenance issues, data processing, reporting activities and forecasting incidents etc.

In this thesis study, it will be carried out to determine the most appropriate area in which artificial intelligence (AI) technology can be used in aviation MRO activities and to detect the most suitable AI tool for this determined area. In the first stage of the study, the potential processes for which AI technology can be used in MRO operations was found out. The WEDBA method, which is one of the multi-criteria decision-making methods, was used to determine which of these potential processes is more suitable for this technology. The next step is to investigate which AI technology tools can be used in the specified process. The most appropriate AI tool for this specified process is determined

by the WEDBA method again. For both applications, criterion weighting is performed by AHP method.

As a result of the study carried out, eight potential fields where the technology can be applied in, and 11 different criteria were determined to decide which of these fields would be more applicable. In this study, it has been determined that the “predictive & preventive maintenance” is the most suitable area according to the result of WEDBA implementation. After this study, a comprehensive market research was conducted for predictive and preventive maintenance applications, and 11 prominent software programs that offer solutions for this field were identified. 13 criteria have been determined to evaluate these software programs while performing the WEDBA method. After all, “Alternative-5” out of 11 alternative AI tools was found to be the most suitable alternative for the implementation of predictive and preventive maintenance in aviation MRO sector. For the further studies, sensitivity analysis can be made through different MCDM methods, and the results can be compared, a feasibility analysis for the determined implementation can be made to investigate whether such an investment is financially feasible or not, and possible project risks can be revealed with a comprehensive risk analysis.

Key Words: artificial intelligence, machine learning, aviation, MRO, maintenance-repair-overhaul, MCDM, AHP, WEDBA

ÖZET

Havacılık sektörü her geçen gün büyümekte ve ulaşım alanındaki etkisini artırmaktadır. Bunun doğal bir sonucu olarak bu sektörde faaliyet gösteren uçak sayısı da giderek artmaktadır. Bu duruma paralel olarak uçuşa elverişlilik ve uçuş emniyeti açısından hayati önem taşıyan bakım-onarım-yenileme (BOY) faaliyetlerinin, belirlenmiş havacılık standartlarına uygun olarak yürütülmesi giderek çok daha karmaşık ve maliyetli hale gelmektedir. Uluslararası otoriteler ve orijinal ekipman üreticileri (OEM'ler) tarafından standartları belirlenen bu faaliyetlerin organize edilmesi ve yeterli kaynaklar tahsis edilerek standartlara uygun bir biçimde bakım planlamalarının düzenlenmesi, havayolu işletmeleri için ciddi bir operasyondur.

Havayolu işletmeleri; uçuş performansını ve güvenliğini artırmanın, bakım-onarım maliyetlerini ve zaman içinde meydana gelen plansız arızaların sayısını en aza indirmenin yollarını aramaktadırlar. Yüzlerce değişken ve birbiriyle bağımlı faktörün olduğu bu denli büyük bir sistemde optimal sonuçlara ulaşmaksa son derece zordur. Ancak teknolojik gelişmeler, birbiriyle ilişkili operasyonel faaliyetler arasındaki veri transferini kolaylaştırmakta ve gerçekleştirilen işlemler sonucunda ortaya çıkan bu büyük veriyi işleyerek anlamlı hale getirebilmektedir. Bu anlamda yapay zeka (YZ) ve makine öğrenmesi temelli teknolojiler; kestirimci ve önleyici bakım, veri işleme, raporlama, olası problemleri önceden tahminleme gibi konularda BOY şirketlerinin büyük destekçisi olmaya aday teknolojilerdir.

Bu araştırmada; havacılık BOY faaliyetlerinde yapay zeka teknolojisinin kullanılabilirliği alanların tespiti, bu alanların uygulanma sırasına göre önceliklendirilmesi ve belirlenen en öncelikli alan için en uygun yapay zeka aracının tespiti gerçekleştirilmiştir. Çalışmanın ilk aşamasında, BOY operasyonlarında yapay zeka teknolojisinin kullanılabilirliği potansiyel alanlar ortaya çıkarılmıştır. Bu potansiyel alanlardan hangisinin BOY süreçleri için daha uygun olduğunu belirlemek amacıyla, çok

kriterli karar verme yöntemlerinden biri olan WEDBA yöntemi kullanılmıştır. Bir sonraki adımda, belirtilen alanda kullanılabilecek potansiyel yapay zeka araçlarına yönelik kapsamlı bir saha çalışması yürütülmüştür. Bir önceki adımda belirlenen alan için en uygun AI aracı ise yine WEDBA yöntemi ile belirlenmiştir. Her iki uygulama için kriterlerin ağırlıklandırılması AHP yöntemi ile yapılmıştır.

Yapılan çalışma sonucunda teknolojinin uygulanabileceği sekiz potansiyel alan ve bu alanlardan hangisinin daha uygulanabilir olacağına karar vermek için de 11 farklı kriter belirlenmiştir. Bu çalışmada, WEDBA uygulamasının sonucuna göre “kestirimci ve önleyici bakım” alanının en uygun alan olduğu belirlenmiştir. Sonrasında, kestirimci ve önleyici bakım uygulamaları için kapsamlı bir pazar araştırması yapılmış ve bu alana yönelik öne çıkan 11 yazılım programı belirlenmiştir. Karar verme çalışmasında bu yazılım programlarının değerlendirilmesi amacıyla 13 kriter belirlenmiştir. Bu çalışmanın sonucu olarak da; havacılık BOY sektöründe, kestirimci ve önleyici bakım uygulaması için 11 alternatif yapay zeka aracından “Alternatif-5”, en uygun alternatif olarak bulunmuştur. Bundan sonra yapılacak çalışmalarda; farklı ÇKKV yöntemleri ile elde edilecek sonuçlar karşılaştırılarak duyarlılık analizi yapılabilir, belirlenen uygulamaya yönelik fizibilite analizi yapılarak böyle bir yatırımın finansal açıdan uygun olup olmadığı araştırılabilir ve kapsamlı bir risk analizi çalışması ile olası proje riskleri ortaya çıkarılabilir.

Anahtar Kelimeler: yapay zeka, havacılık, MRO, BOY, bakım-onarım-yenileme, ÇÖKV, ÇKKV, AHP, WEDBA

1. INTRODUCTION

Today, humanity is experiencing an era where speed is much more important compared to previous periods in both business and social activities. In response to this need, airline transport, which is the fastest way of transportation, is increasing its importance. Depending on this trend, there is a significant increase in the number of aircraft operating in this sector every year. Therefore, the maintenance and repair activities of these aircraft become a serious operation that must be carried out professionally. According to the International Air Transport Association (2020), it was reported that commercial airlines had carried out their business operations with a total of 27343 aircraft (apart from this, approximately 3200 aircraft stored in parking positions) in 2019, and they had spent 82 billion Dollar on MRO activities for those aircraft, which amounts to be about 10% of all operational costs. Also, in the report for 2020 prepared by IATA (2021), it was stated that airline companies carried out their activities with a total of 30771 aircraft, those of which 9486 were out of service and stored in parking positions, especially due to the reason of the Covid-19 pandemic. In such a large-scale industry, a small improvement in operational processes provides companies with substantial financial benefits. On the other hand, it is a serious operation for the operators to organize these activities determined by international authorities and original equipment manufacturers (OEMs) and to arrange maintenance schedules with allocating adequate resources. At this point, digitalization, and innovative technologies (such as artificial intelligence, internet of things, blockchain, etc.) offer great contributions and opportunities to reduce costs and increase profitability for airline companies.

The usage areas of artificial intelligence technology, which aim to robotize and accelerate the processes by minimizing the human factor, are gradually expanding. Although artificial intelligence technology has been studied for many years, it has recently begun to take its place in the aviation sector. Actually, there are more potential areas of use than areas in aviation that are actively used. Especially in aviation MRO processes where

failure tolerance originating from human factor is almost zero, using of this technology can contribute to both preventing potential major problems (incident, accident, etc.) and reducing costs by making processes more efficient and effective.

The purpose of this article is to conduct a comprehensive research on the use of artificial intelligence technology in aviation MRO sector and to reveal its potential fields and opportunities, and to help decision makers to be able to prioritize them by presenting their positive and negative impact on processes through MCDM techniques. Contrary to the studies in the literature, which reveal potential usage areas and application methodologies in aviation, a comprehensive view of these areas and determination of the most appropriate process and tool using MCDM is carried out in this paper.

The structure of the paper is as follows: First, the researches in the literature, which deal with aviation, MRO and AI topics are included in Sect. 2. Then, general information on artificial intelligence technology and aviation MRO activities are given under Sections 3 and 4, respectively. After that, under Section 5, the opportunities of artificial intelligence technology that can be applied in aviation MRO activities are mentioned. Alternative usage opportunities regarding which areas AI can be used are revealed and prioritized with the WEDBA method in Sect. 6. Thereafter, in Sect. 7, the potential AI tools are identified for the highest priority process and the most suitable AI tool for the determined process is determined by using the WEDBA method. Finally, the results of the whole study are discussed and recommendations for future researches are offered under Section 8.

2. LITERATURE REVIEW

The concept of AI, which dates back to the mid-20th century and emerged with the concept of “computing machines and thinking machines” by Alan Turing, is defined as the ability to read and correctly interpret the data flowing from the environment, to learn from this data and to use these learnings in order to achieve specific missions and objectives through flexible adaptation (Haenlain and Kaplan, 2019). Today, AI technology, which is used in many fields and sectors together with machine learning and deep learning sub-concepts, is gaining importance in the aviation industry day by day and considerable steps are being taken towards its use (EASA, 2020).

Throughout the literature review, it had been benefited from various scientific databases such as “Web of Science”, “Science Direct”, “Google Scholar”, “IEEE Xplore”, and “SpringerLink”. Articles and researches in these databases, most of which were published in the last five years, and containing the keywords of “aviation”, “artificial intelligence”, “aviation maintenance, repair and overhaul”, “machine learning”, “deep learning”, “artificial neural networks”, “project selection”, “multi-criteria decision-making” have been reviewed. It has been observed that researches on the use of AI in the aviation industry are limited, and there are a couple of studies based on aviation MRO in the literature. Also, it is noticed that these studies are mostly ones aimed at revealing potential usage areas, application methodologies and roadmaps.

Chen and Juang (2022) carry out a study on the establishment of an artificial intelligence-supported inspection mechanism to detect anomalies of aircraft components in maintenance period. In their articles, they refer to two similar aircraft incidents that caused engine loss by damage of turbofan jet blades that were not detected the fatigue in visual inspection during the previous maintenance. They mentioned the importance of artificial intelligence assisted inspection to detect of structural damage and material fatigue that cannot be detected by human control in terms of flight safety.

Amin et al. (2022) conduct a research on the use of natural language processing, a sub-field of artificial intelligence technology, in the aviation industry. They mention that this technology can be used in aviation MRO to review, classify, and verify logbook records to predict possible failures earlier, as well as to assist MRO technicians when reviewing maintenance manuals and documents.

Garcia et al. (2021) mention that AI and ML technology can be used to overcome the problems in aviation cyber security, and they emphasize possible challenges by drawing up the usage methods, roadmap, and challenges.

Vincent et al. (2021) detail the opportunities and benefits that AI can offer to the industry by giving examples of today's usages and impacts for aviation and space industry. They detail the uses and effects of AI technology in passenger identification, baggage identification, customer satisfaction, aircraft safety and maintenance, and remote sensing.

Ning et al. (2021) mention that huge data about the health of the aircraft and its components are created and shared by way of sensors, thanks to the developing avionics technologies in the aviation sector. They point out in the article that by interpreting this data through deep learning, great advances can be made in the field of predictive maintenance and so anomalies can be predicted earlier.

Fayek et al. (2021) carry out a study on the development of a data-driven model through artificial neural networks that will provide an assessment of the health of the aircraft structure by interpreting the strain level data to which an aircraft is exposed. In this way, they draw attention to the fact that a more modern approach to the management of the health of the airframe will be displayed and that more efficient results can be obtained in terms of maintenance scheduling and the supply of necessary parts, thanks to the predictive condition-based planning to aircraft maintenance.

In the research of Apostolidis et al. (2020), there are various opinions in their article on the importance of AI-ML-based Data Analytics in MRO operations and how developments in this field will contribute positively to aviation MRO processes in terms

of optimization and forecasting. In another study, Apostolidis and Staopolis (2021) conduct a case study on how it will contribute to MRO processes by introducing the concept of artificial intelligence-based digital twin.

In her article, Çankaya (2020) reveals separately in which areas the concepts of artificial neural networks, expert systems, fuzzy logic, and machine learning, which are sub-components of artificial intelligence, can be used in the aviation ecosystem.

Kulida and Lebedev (2020) discuss AI trends that are used in solving problems in civil and military aviation industry and that can be used in the future and talk about their advantages and disadvantages. They also mention that an artificial intelligence assisted diagnostic system can be established to evaluate the technical condition of an aircraft and to predict potential problems.

Shukla et al. (2020) conduct a research about revealing the importance and the need of explainable artificial intelligence for aviation MRO sector while taking advantage of deep neural network for predictive maintenance processes. In order to improve the perspective on neural networks in a positive way, they mention that there is a great opportunity for the aviation MRO sector by emphasizing the advanced studies in this artificial intelligence field in recent years.

Bouarfa et al. (2020) model an automated visual inspection system that can detect damage on the aircraft using artificial intelligence technology. The model has been supported by a recently developed neural network architecture that can classify faults such as lightning strikes, paint damage, cracks, holes, and corrosion challenged on the aircraft even if the training set is very limited. Thus, the visual inspection process can be facilitated and accelerated, and the rate of incident risk can be reduced by preventing human error-induced overlook.

Wang et al. (2020) draw attention to the fact that the visual inspection and damage detection processes during maintenance-repair will be significantly improved in virtue of

deep learning algorithm to be integrated into the augmented reality glasses in their published article.

Pelt et al. (2019) carry out a comprehensive study on the importance and use of data in aviation MRO in their article on “Data Mining in MRO”. They point out that machine learning, which is the sub-field of artificial intelligence, can have two main goals in data analytics in aviation MRO, namely inference and prediction.

Kaparathi and Bumblauskas (2019) conduct a study on an algorithm with the ML approach to predetermine possible failures related with maintenance of an aircraft and to plan maintenance time in a more optimized way.

Zeldam et al. (2018) study on an AI-based model for the automated detection of anomalies and diagnosing failures on aviation maintenance cards by way of developing a model that can be compared the maintenance data and usage data. Thus, it is aimed to prevent the incorrect and/or poor maintenance by minimizing human error factor.

Rengasamy et al. (2018) conduct a series of research on the applications of deep learning in the aviation MRO industry and obtained results for its use in four main architectures: Deep Autoencoders, Long Short-Term Memory, Convolutional Neural Networks and Deep Belief Networks. In their article, they review what problem these architectures can be used to overcome in this industry, reveal the weaknesses for each application scenario and mention the implementation outputs.

Amirkolaii et al. (2017) aim to show in their research that inventory costs can be reduced by improving the management of the spare parts supply chain, which has high demand uncertainty and fluctuation in the aviation MRO sector, by help of an artificial intelligence data-driven system. They have also revealed the best neural network algorithm by making benchmark tests supporting with different scenarios.

Cheng and Li (2016) establish an artificial neural network algorithm model, present a study on how this model can be applied in aviation, and analyze the prospects and difficulties of the application.

Table 2.1: Detailed references of literature review

	Title	Year	Author(s)
1	YOLOv4 Object Detection Model for Nondestructive Radiographic Testing in Aviation Maintenance Tasks.	2022	Zhi-Hao Chen, Jyh-Ching Juang
2	Exploration of Natural Language Processing (NLP) Applications in Aviation	2022	Nadine Amin, Tracy L. Yother, Mary E. Johnson, Julia Rayz
3	Artificial Intelligence and Machine Learning Approaches For Aviation Cybersecurity: An Overview	2021	Anna Baron Garcia, Radu F. Babiceanu, Remzi Seker
4	Impact of Artificial Intelligence in the Aviation and Space Sector	2021	Nelvin Chummar Vincent, Roshan Rajesh Bhakar, Sarath Raj Nadarajan Assari Syamala, Jerrin Varghese
5	Applications of deep learning in big data analytics for aircraft complex system anomaly detection	2021	Shungang Ning, Jianzhong Sun, Cui Liu, Yang Yi
6	Deep learning airframe load prediction: A data-driven system for aircraft structural health management	2021	Haytham M. Fayek, Michael Candon, Oleg Levinski, Stephan Koschel, Pier Marzocca
7	An AI-based Digital Twin Case Study in the MRO Sector	2021	Asteris Apostolidis, Konstantinos P. Stamoulis

8	Aviation Data Analytics in MRO Operations: Prospects and Pitfalls	2020	Asteris Apostolidis, Maurice Pelt, Konstantinos P. Stamoulis
9	Artificial Intelligence, API and Big Data Based Solutions Spreading in Aviation	2020	Didem Çankaya
10	About the Use of Artificial Intelligence Methods in Aviation	2020	Elena Kulida, Valentin Lebedev
11	Opportunities for Explainable Artificial Intelligence in Aerospace Predictive Maintenance	2020	Bibhudhendu Shukla, Ip-Shing Fan, I.K. Jennions
12	Towards Automated Aircraft Maintenance Inspection. A use case of detecting aircraft dents using Mask R-CNN	2020	Soufiane Bouarfa, Anıl Doğru, Ridwan Arizar, Reyhan Aydoğan, Joselito Serafico
13	Augmented reality for enhanced visual inspection through knowledge-based deep learning	2020	Shaohan Wang, Sakib Ashraf Zargar, Fuh-Gwo Yuan
14	Data Mining in MRO: Centre for Applied Research Technology	2019	Asteris Apostolidis, Robert J. de Boer, Roberto S. Félix Patrón, Konstantinos Stamoulis
15	Designing predictive maintenance systems using decision tree-based machine learning techniques	2019	Shashidhar Kaparathi, Daniel Bumblauskas
16	Automated Failure Diagnosis in Aviation Maintenance Using eXplainable Artificial Intelligence (XAI)	2018	Sophie ten Zeldam, Arjan de Jong, Richard Loendersloot, Tiedo Tinga

17	Deep Learning Approaches to Aircraft Maintenance, Repair and Overhaul: A Review	2018	Divish Rengasamy, Herve P. Morvan, Graziela P. Figueredo
18	Demand Forecasting for Irregular Demands in Business Aircraft Spare Parts Supply Chains by using Artificial Intelligence (AI)	2017	K. Nemati Amirkolaii, A. Baboli, M. K. Shahzad, R. Tonadre
19	Research Status of Artificial Neural Network and Its Application Assumption in Aviation	2016	Tao-ran Cheng, Peng-cheng Wen, Yang Li

3. ARTIFICIAL INTELLIGENCE TECHNOLOGY

The use of artificial intelligence technology and its impact on the business world is increasing every year, with the impact of massive data generated in the increasingly globalized digital world. It is an undeniable fact that this technology, which produces breakthrough outcomes in terms of efficiency, effectivity, and productivity, is going to reach much more advanced dimensions, due to reasons such as the use of limited resources becoming more important with the increase in world population, and the incredible number of companies competing with each other in a particular sector etc. In the artificial intelligence technology report prepared by PWC in 2017, it is stated that the impact of AI technology on the global gross domestic product, which was approximately 1.3 trillion dollars in 2017, is expected to reach 15.7 trillion dollars in 2030. Similarly, McKinsey predicts that this figure will be 13 trillion dollars in the report prepared in 2018.

3.1. Definition of Artificial Technology

Although there are many different definitions, artificial intelligence in its most general form is a software system that interprets the data it collects from the environment, trains itself and provides meaningful outputs similar to human thoughts, behaviors, and mimics. AI-driven computer systems can be used in different ways depending on their purpose and role: they can present raw or processed data that can help human in the decision-making process, they can perform certain routine tasks, or they can be direct decision-makers by making inferences from the data.

Artificial intelligence works with different algorithms and models according to the function and purpose of use. Although there are many branches, the main sub-fields of it are machine learning, artificial neural networks, and deep learning (Figure 3.1). Therewithal, natural language processing, computer vision, and cognitive computing can

be also categorized as different fields of artificial intelligence.

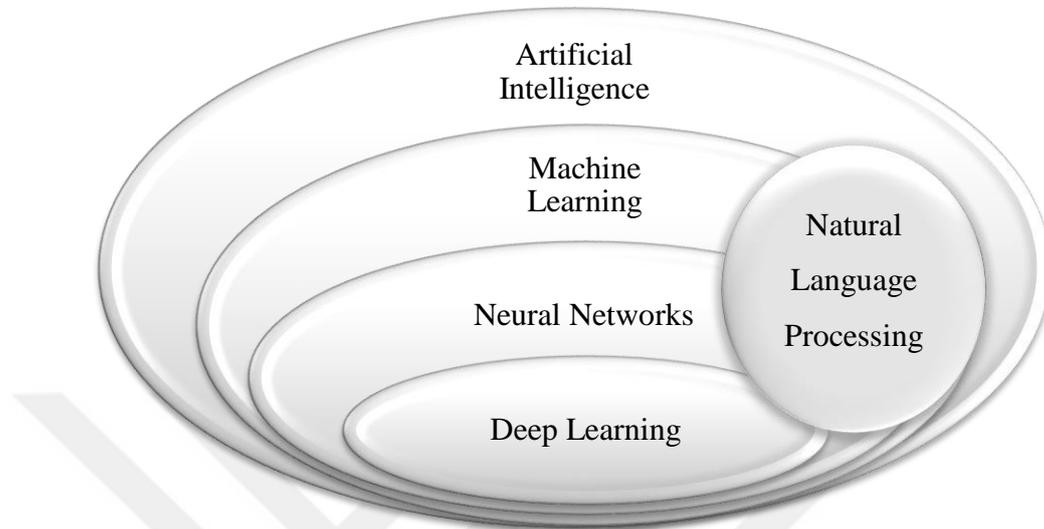


Figure 3.1: The hierarchy and sub-fields of AI

Machine Learning: It is a sub-branch of artificial intelligence, where the system produces outputs by interpreting and experiencing existing inputs, without having to define outputs to the system. Automated vehicles, online search suggestions, optimal routing can be given as examples of this field.

Artificial Neural Networks: Artificial neural network, which is a sub-component of machine learning, imitates the neurological working principle of the human brain. It associates and categorizes data by establishing meaningful connections between inputs in a large data set. It then tries to give meaningful outputs generally about future by establishing a relation like a cause-effect relationship. Its usage missions are generally predicting, forecasting, and analyzing.

Deep Learning: Deep learning, a subcomponent of the artificial neural network and also can be called a self-learned machine, aims to reach the most accurate and meaningful output in a short time by layering and classifying the data collected from the environment.

The recognition of voice and image, the determination of gesture and emotion, the detection of fault, error and fraud are the most used areas.

Natural Language Processing: It is a system that aims to recognize the human voice, to interpret and evaluate the speech and/or written sources, and to be able to give harmonious answers and/or take actions according to the given command. Online voice assistants, chat-bots and e-mail spam detectors are examples of this field.

Computer Vision: It is an AI technology component that allows all features in visual data to be identified, interpreted, and processed. It is used in very important areas such as taking necessary actions by scanning documents, evaluating MRI results, interpreting X-RAY images, and automating visual inspections etc.

Cognitive Computing: It is aimed to provide machines with human-like behaviors and information processing capabilities, and to make human-machine relationships more efficient in this system. Human-like reactions are tried to be given by interpreting the stimuli in the environment. Self-driven cars and robotic devices can be shown as examples of their use in this area.

3.2. Advantages and Disadvantages

The advantages that artificial intelligence technology brings to human life are an obvious fact and these advantages of this technology can be listed lengthily. However, if these benefits are categorized, the following results emerge:

- Minimizing errors sourced by human factor
- Performing routine tasks continuously and quickly without interruption
- Making huge data meaningful and solving complex algorithms in a short time
- Decision making rationally rather than emotionally

On the other hand, there are some disadvantages for artificial intelligence technology. The concerns about this technology can be classified as:

- Cost of equipment and necessary software tools

- Lack of responsibility for erroneous or criminal results, ethical and moral concerns
- Increase in unemployment rate
- Loss of income as a result of the multitude of frequent breakdowns and/or wrong actions
- Laziness and decrease in worker productivity

Before adapting this technology to a business process, all the pros and cons of the technology should be considered by decision makers, and a rigorous feasibility and risk analysis should be performed.

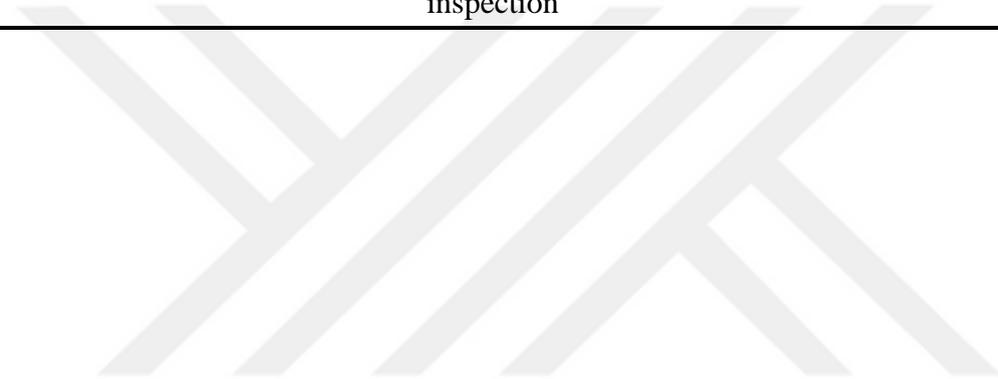
3.3. Fields of Usage

AI technology, which emerged in the Second World War to decrypt encrypted enemy communication system, is used in many sectors today and is expanding its usage network day by day. According to PWC (2017), there are eight key sectors to be applied to this technology due to its impact and potentiality. These are listed as shown below:

Table 3.1: The sector and fields of usage of AI technology

Sector	Fields of Usage
Healthcare	Supporting diagnosis, early identification of diseases and pandemics, interpreting medical inspections
Automotive	Autonomous vehicles, semi-autonomous features, predictive and autonomous maintenance
Financial Services	Personalized financial planning, preventing illegal cash flow and detection of fraud, process automation
Transportation and Logistic	Autonomous delivery, optimized routing, cognitive tracking

Technology, Communications and Entertainment	Media archiving and search, personalized content creation and marketing & advertising
Retail	Personalized production and design, forecasting customer demand, delivery, and inventory management
Energy	Cognitive metering, optimized network operations and smart storage, predictive maintenance of infrastructure
Manufacturing	Supply chain management and manufacturing optimization, demand driven production, effective manufacturing processes and atomized monitoring & inspection



4. MAINTENANCE, REPAIR AND OVERHAUL (MRO) in AVIATION INDUSTRY

Depending on the development of air transport and the increase in the number of aircraft, the aviation MRO sector is also growing. The financial size of the aviation MRO sector, one of the most critical and important branches of airline transport, was 87 billion dollars in 2021. It is expected to reach approximately 130 billion dollars in 2030, and its CAGR between the years of 2022 and 2030 is expected to be 4.57% (GWR, 2022). Innovative steps to be taken for such a large and rapidly developing sector will contribute both greatly to the financial statement of the sector and to the improvement of flight safety.

4.1. Definition of MRO

In the most general sense, MRO can be considered as “all actions with the purpose of keeping or restoring an item in a state where it can perform its required function. Actions include the combination of all technical, supervisory, and related administrative actions” (EFNMS, 2013).

In aviation industry, aircraft maintenance is carried out by MRO Organizations (THY Technic, Lufthansa Technik, etc.) authorized by civil aviation authorities (IATA, FAA, SHGM, etc.) to ensure safety in flight activities, to ensure that the aircraft is ready for flight, and to reduce costs without compromising the safety factor.

Authorized MRO Organizations within the scope of the authorization obtained from civil aviation authorities; It provides maintenance services, including all service activities, control activities, maintenance activities, repair activities, modification activities and revision activities in order to keep the aircraft in a suitable condition (airworthiness) for flight during the period from the production of the aircraft until the end of its service life. According to the Vieira and Loures (2016), the MRO costs of an aircraft is very costly

since MRO operations have strict rules and regulations under the supervision of authorities and all components of the aircraft must have licensed and certified by Aircraft Original Equipment Manufacturers (OEMs) such as Airbus, Boeing, Bombardier, Embraer, Gulfstream, etc. Therefore, airline companies spend billions of dollars each year on maintenance activities, which form part of their operational activities, i.e., 12 - 15% of total operating cost (IATA, 2020), to meet such requirements. They are also making great efforts to carry out this complex operation that includes many variables.

4.2. MRO Units and Processes

As in every major organization, various operational and institutional units are established in the aviation MRO sector in order to carry out the required activities professionally. These units work in coordination with each other and make an effort to carry out the most proper maintenance and repair of an aircraft in the shortest time with the least cost.

4.2.1. Line Maintenance

Line Maintenance includes “Transit, daily or 48h”, “A” and “B” checks, which are narrower than base maintenance, and include superficial repairs, maintenance, and controls. “Transit, daily or 48h” check is performed every time the aircraft stops or will stay on the ground for more than 4 hours, to detect and to check visible damage and deteriorations on the aircraft, such as checking fluid levels and emergency equipment, inspecting wheels and brakes. “A” check is a control performed in the hangar after every 400 flight hours (FH) or every 2 months, which the access panel is opened, and certain parts are checked and serviced with some limited special tooling, servicing, and test equipment. For example, general external visual inspection of aircraft structure for evidence of damage, deformation, corrosion, missing parts; crew oxygen system pressure check; operationally check emergency lights, etc. “B” check is a control performed in the hangar after every 1100 flight hours (FH), which requires more detailed check of components and systems with again some limited special tooling, servicing, and test equipment, but not include detailed disassembly or removal of components.

4.2.2. Base Maintenance

Base Maintenance includes “C” and “D” checks, which are broader than line maintenance, and includes removal and disassembly of components. Both are performed in a hangar with some extensive tooling, test equipment, and require personnel who have special skill levels. Upper controls include the lower controls, such as C checks include daily, A and B checks. While C checks performed every 4000 FH or 20 months and last 3 or 5 days, D checks performed every 25000 FH or 6 years and last 20 or more days (Kinnison & Siddiqui, 2013).

4.2.3. Production Planning and Control

Production Planning and Control can be called the heart of aircraft maintenance and repair activities. In order to organize base and line maintenance of all aircraft in the fleet of an aircraft company; time, place, material, equipment, and personnel adjustments are made and forecasting of possible non-routine maintenance are realized. For this reason, this unit is in intense contact with all other units in an MRO activity. Its activities have difficult tasks such as planning, forecasting, resource allocation, optimization, controlling, fleet arrangement in which many variable and stochastic parameters are taken into account. Since very large calculations are made while planning and controlling, informatics support is of great importance in this activity.

4.2.4. Quality Assurance and Control

Quality Assurance and Control units are responsible for the implementation and supervision of all maintenance processes in an MRO activity in accordance with the competencies determined by the authorities, original equipment manufacturers and independent quality auditors. It checks the compliance of all equipment, materials, work processes and workforce standards according to the determined criteria and develops projects to increase the quality standard and efficiency of the company. It reports unsafe and risky situations and warns related units to take necessary precautions.

4.2.5. Engineering - Authorization

The engineering department in an MRO company is responsible for maintenance procedures and maintenance manuals. It analyzes and evaluates the necessary updates to these procedures, determines the requirements and creates the maintenance program. It makes the feasibility study and determines the technical details of the modifications to be made on the aircraft or the part. Its main tasks can be listed as follows:

- AD and SB evaluation
- Maintenance program preparation and update
- Maintenance packages and maintenance cards creation and update
- Customer specific MEL preparation and update
- Maintenance documents and manuals management
- Aircraft configuration management
- EO (Engineering Order) preparation and distribution

4.2.6. Material Planning

The material planning department performs one of the most important and big operations in aircraft MRO. A commercial airplane consists of millions of parts, most of which are called components. Boeing says that the 747-8 has about six million parts manufactured by more than 550 suppliers in almost 30 countries, including the United States, China, Germany, Japan, South Korea, and the United Kingdom (Everett, 2013). It is possible to categorize the parts into five major areas for an airplane: fuselage, wings, stabilizer, engine, landing gear, which are made up of thousands of tinier components. The airworthiness of an aircraft depends on the healthiness, safety, and reliability of all these components. In the aviation industry, time is the most vital component of the system to run the operation successfully. Therefore, in this industry, ease of access to spare parts is essential in the event of damage, malfunction, or maintenance process. As a result of this situation, MRO Organizations have to keep a very high level of spare parts inventory in order to respond very quickly to instant needs. For example, Lufthansa Technik, which operates one of the largest aircraft component pools in the world, has 2.3 billion Dollar worth of components in their stocks (LT, 2021).

The success of spare part management operation depends on the ability tracing and tracking the components both inside the company and throughout the supply chain. All the records of movement, change, repair, store, modification, maintenance, ownership of a component must be clearly and reliably stored in order for assuring the aircraft airworthiness. However, this complex management has some difficulties to conduct due to some reasons:

- An airplane may contain millions of unique parts
- A component can be subjected to many different processes: installation, removal, repair, maintenance, storage, shipment, hand-over
- Complex supply chain structure, rules, and regulations

Therefore, the correct transfer of information between stakeholders (MRO Organizations, Airlines, Authorities, OEMs, suppliers, etc.) and ensuring continuity of information can facilitate inventory management, prevent fraud (counterfeit components), obey legislation and lead to serious cost reductions in operation. At this point, IoT and blockchain technologies can be very useful to coordinate the system smoothly and successfully (Rajkov, 2018).

As mentioned before, the large number of parts of the aircraft causes means many spare parts are kept in the inventory for repair and maintenance. As a natural consequence of this, the storage and inventory management costs of airline companies increase. In order to overcome this situation, airlines have preferred to use the pool inventory system. In the logic of this system, spare parts in the pool are available to the stakeholders instantly, and a component (unserviceable) that breaks down or needs maintenance when needed can be procured with a working component (serviceable) from MRO Organization. In return, MRO organizations charge an annual fee from airlines to make the components serviceable by maintaining and repairing unserviceable components. In this contract form in which the effects of game theory are seen, it is not known which of the parties will benefit at the end of the contract date. Thanks to this partnership, airline companies can quickly access the parts they need and reduce inventory costs, while on the other hand, MRO companies earn a profit by taking maintenance fees.

4.2.7. Sales & Marketing

The sales and marketing department within an MRO company performs the following duties:

- Managing the sales and marketing processes of the products and services sold,
- Managing all kinds of relations with customers,
- Managing internal and external communication activities,
- Determining the investments and strategic partnerships to be made and putting them into action,
- Making and reporting the necessary competitor, product and market analyzes,
- Reporting on all the activities carried out by the institution during a year.

4.2.8. Purchasing and Logistic

In an MRO operation, taking delivery of millions of parts, equipment, and materials occurs each year. The purchasing and logistics unit is responsible for the purchasing, logistics and storage of those materials and equipment needed in an MRO activity. It conducts market research for the materials and equipment needed, opens tenders, if necessary, manages the process of purchasing things from the supplier company to the company warehouse, and manages the storage of all materials and equipment.

4.2.9. Financial Affairs

Financial affairs are responsible for the management of income and expenditure accounts in an organization. It carries out all the financial processes of the company such as making the payment of the purchases, invoicing the sales, tax payments, personnel payments, dividend distribution, issuing the annual balance sheet, budget control, execution of the finances, etc.

4.2.10. Human Resources and Training

Skilled human resources are vital to an MRO company. No aircraft's maintenance process can be completed and so cannot participate in flight activities without the approval of an authorized technician with the required certification, given by national and international aviation authorities. The technician who will maintain an aircraft or a part must have received the necessary trainings, passed the exams successfully, and have a certain experience in order to have necessary certification with the standards set by international institutions and organizations. These training courses and exams must be applied to aircraft technicians in certain periods and their follow-up is the responsibility of the MRO company. Likewise, other employees of the company must have received compulsory training in certain periods in order to ensure flight safety and security and must have successfully passed the exams to be held after the training.

In addition, the company has to ensure maximum occupational health and safety for its employees. In order to achieve this, it is necessary to take all necessary precautions against possible accidents and to train its personnel. In order to ensure the highest level of flight safety; processes such as supplying well-equipped personnel to the company, training of existing personnel, keeping morale and motivation high, and ensuring occupational health and safety should be carried out meticulously.

5. ARTIFICIAL INTELLIGENCE APPLICATIONS IN MRO

Artificial Intelligence technology has started to take an active role in various sectors in different areas. There are also several potential areas where this technology can be used in aviation MRO operations. In this research, as it is mentioned in Sect. 1, application area prioritization will be made for a company that has not yet integrated AI technology into any of its processes. In this sense, research has been conducted on the areas where AI technology can be used in the aviation MRO sector by considering the MRO processes outlined under Section 4, and it has been determined that this technology can be integrated into eight different processes, most of which are mentioned in the literature review section: Document Management (A1)¹, Augmented Reality (A2), Anomaly Detection (A3), Recruitment (A4), Supply Chain Optimization (A5), Predictive & Preventive Maintenance (A6), Maintenance Scheduling (A7), and Automated Quality Control (A8).

5.1. Document Management

All operations to be carried out and to be performed in aircraft maintenance and repair activities are documented in detail by OEM and MRO firms (such as aircraft maintenance manual-AMM, component maintenance manual-CMM, airworthiness directive-AD, service bulletin-SB, etc.), and all transactions are recorded step by step (such as task cards, engineering orders, work orders, invoices, engineering coordination sheets, etc.). As a result, a huge amount of data is created and should be stored properly. Managing this big data and accessing the necessary information quickly is very important for an employee in the operational processes. At this point, artificial intelligence technology provides a better solution for companies in terms of fast documentation and easiness of information access. Faster and easier scanning, processing, classifying, and transferring of documents and categorizing according to their contents procures great convenience in

¹ indicates Alternative-1.

terms of accessing information by using image processing.

5.2. Augmented Reality

More effective results can be obtained from VR glasses, which are used as a guide when training personnel and performing complex work. Using augmented reality, especially in technical training of technicians, and following the process steps with the help of glasses in complex maintenance operations will both benefit in terms of man-hour gain and reduce the risk of erroneous operations. For example, a technician can follow the seat removal procedure instantly while removing the seat in the aircraft and does not need the aircraft maintenance manual. As another example, Johnson (1990) says that AI technology can be used as an intelligent tutoring system in aircraft maintenance training.

5.3. Anomaly Detection

Drones equipped with AI-powered cameras can be used to detect structural damage and problems on the aircraft. It is obvious that much more effective and faster results will be obtained when making use of drones, especially in assessment the extent of the damage when occurring foreign object collisions or in visual inspections during aircraft purchases and sales, when compared to the human perspective.

5.4. Recruitment

During the recruitment processes, thousands of candidate applications are taken for a limited number of technical and engineering positions. Making the pre-selection based on artificial intelligence in selecting the most suitable candidate for the open positions can contribute to serious acceleration and more effective results in the recruitment processes.

5.5. Supply Chain Optimization

Keeping the maintenance period of an aircraft as short as possible is of great importance for the profitability of airline companies. Although it varies according to the size of the plane, not flying for even an hour of an aircraft means a loss of thousands of dollars for an airline company. Therefore, it is of great importance that the materials, components, and equipment required for maintenance are in the right place at the right time. In an industry where there are thousands of various suppliers spread around the world for thousands of different parts, it is almost impossible for human abilities to properly adjust and optimize the supply chain. For this reason, considering the amount of the part that should be stored in the warehouse, and other factors, especially the transportation times of them, the inclusion of an artificial intelligence-based program which is able to provide alternative solutions much faster will help to create a much smoother supply chain for an MRO company especially by making more accurate forecast and deeply analyzing the past data for demand and supply via machine learning.

5.6. Predictive & Preventive Maintenance

For aircraft maintenance activities, it is very important for flight safety and customer satisfaction to prevent possible accidents and AOG (aircraft-on-ground) situations, where a component is carried out maintenance without deteriorating or damaged, or renewed when necessary. For this reason, determining the maintenance and renewal periods of a component in the aircraft, and taking into account the past maintenance and repair records provide great financial and reputation gains to the airline companies. In addition, by making use of the Internet of Things, it can be taken the necessary actions before the part becomes unserviceable by collecting instant data via sensors to be mounted on the necessary parts and constantly evaluating the data through artificial intelligence, also makes a great contribution to the same purpose.

5.7. Maintenance Scheduling

Arrangement of an aircraft's maintenance schedule is one of the most challenging tasks among the maintenance processes. The issues of when an aircraft will be taken into

systems will be included in the maintenance package, and which personnel will be involved in maintenance program are challenging for engineers and managers due to many variable factors. An AI-assisted software can create a planning schedule that is close to optimal results, taking this adjustment into account many variable factors. In this way, a system can be established in which unnecessary maintenance steps and processes are eliminated and in which resource allocation is made more effective and efficient.

5.8. Automated Quality Control

Besides the maintenance operations are planned effectively and carried out properly, it is of great importance for MRO companies that the execution of the operations in accordance with the rules, regulations, and procedures with regards to airworthiness and flight safety. At this point, robotizing document checks and visual inspections with artificial intelligence-based systems may contribute to the aircraft, whose maintenance has been completed, leaving the hangar, and participating in flight activities in a shorter time.

6. USING MULTI CRITERIA DECISION MAKING (MCDM) METHODS on WHICH AREAS to APPLY AI TECHNOLOGY APPLICATIONS in MRO

As it is known, adapting new technologies to old systems is very difficult, time-consuming, and costly. Therefore, it may not be a logical and profitable move to make changes in every area in the current system. Before making system and technology changes, in order to decide on which areas of the system requires development and how much the resource transfer to this specific fields of the system will be made, the importance of the criteria of the system should be determined by considering into the needs of the system. The returns of the investment should be calculated and planned in advance. At this point, using methods, calculation, and planning tools of MCDM are among the rational solutions.

As mentioned before, MRO is a costly activity that includes many variable factors, whose processes are very complex, and where the uncertainty is at a very high level. Therefore, both financially and operationally, it is not feasible to apply blockchain and IoT technologies to every field of this system. For this reason, the criteria and factors that are important for the activities in the MRO should be determined, the importance of these criteria in the whole system should be evaluated, the processes that will contribute most to the system economically and operationally should be revealed, and after all new technologies should be adapted to these processes.

MCDM is based on the process of modeling the decision process according to criteria and analyzing it in a way that maximizes the benefit that the decision maker will gain at the end of the process (Khan et al., 2018). The applying MCDM procedures are as shown below list (Singh & Malik, 2014):

1. Identifying the real problem of the activity that includes aim of the study, alternative scenarios, decision makers, shareholders, key performance indicators and expected output.

2. Indicating criteria which will affect the output of the project that decision makers and stakeholders give important
3. Measuring the performance of the criteria with the determined key performance indicators
4. Scoring scenarios' performances taking into account the importance of the criteria
5. Weighting the criteria relevant to the achievements for the project
6. Ranking the alternative scenarios by taking consideration of the scores and the criteria weights
7. Deciding the alternative by supporting the decision makers with MCDM outputs and feasibility analysis.

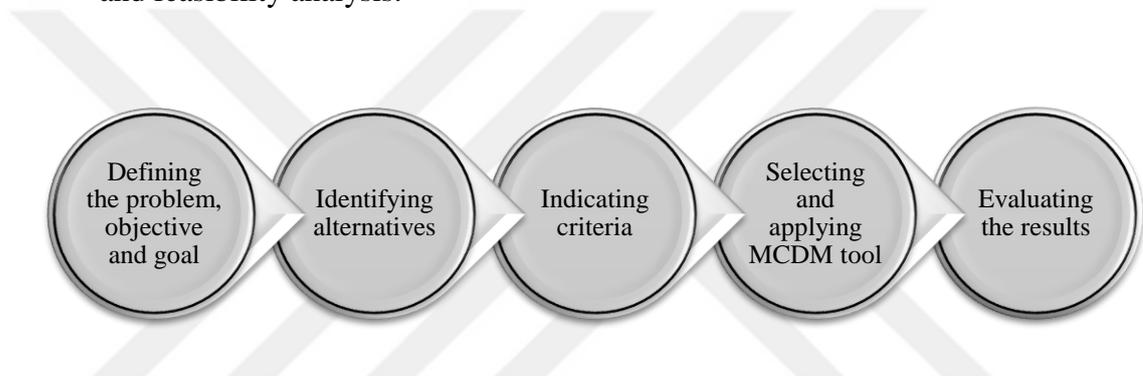


Figure 6.1: Overview of the MCDM process

6.1. Defining Criteria for Selection of MRO Process to Use AI

In the previous section of 5, it was mentioned that AI technology can be used in eight different areas of MRO processes. As it is known that adapting a technological innovation to a process is costly and toilsome. Therefore, decision makers want to act cautiously by considering some criteria when deciding to make a technological investment. After an MRO company decides to integrate AI technology into its processes, it should consider some important criteria when deciding in which area it should primarily use this technology. These criteria also have different ratings when making decisions. 11 criteria have been identified that can help to decide in which area of MRO activities will be applied. Some processes described in the previous chapter (Section 5) have a direct impact positively on some of the following main criteria, which are important for

maintenance operations, while the impact on others is less. While integrating innovation to the MRO processes, the positive correlation of the new technology with the following criteria should be considered: Airworthiness (C1)², Flight Safety (C2), Customer Satisfaction (C3), Employee Acceptance (C4), Maintenance Cost (C5), Revenue Growth (C6), Maintenance Time (C7), Occupational Health & Safety (C8), Business Quality (C9), Reputation (C10), and Applicability (C11).

Airworthiness: It means suitability of an aircraft with regards to meeting physical requirements to complete a flight safely. Continuous airworthiness is a mandatory condition to maintain an airline's operations without interruption, i.e., AOG (aircraft-on-ground) situation.

Flight Safety: Although it is similar to airworthiness, it means that airplanes can safely perform their flights without experiencing accident-incident-breakdown-defect situations. Performing maintenance procedures in accordance with the rules without disruption is among the most important duties of an MRO and airline company in terms of flight safety.

Customer Satisfaction: Among the customers of MRO companies are mostly commercial airlines with large fleets consisting of many aircraft. As in every commercial activity, customer satisfaction is of great importance for the continuity and progress of financial gain in this sector as well. Since quickness, job quality and information transparency are priority issues in the aircraft maintenance industry, digitalization has become directly related to customer satisfaction.

Employee Acceptance: In order to get benefit from an innovation to be made in a maintenance process, the satisfaction and opinion of the personnel who will be affected by the change is important. A change that will create a workload greater than the current workload for a member of staff or an innovation that is difficult to use and understand will reduce employee satisfaction and lead to a decrease in productivity. For this reason,

² indicates Criteria-1.

it is necessary to offer easy-to-use and understandable innovations that will facilitate the work of technical personnel.

Maintenance Cost: One of the common goals of the MRO industry, as it is the common goal of almost every industry, is to reduce operational costs. Elimination of unnecessary steps in the processes, avoiding waste by using materials, equipment and workforce effectively are several of the key points of cost reduction. Especially digital approaches are activities that directly affect this purpose positively.

Revenue Growth: The main goal of commercial activities is to generate income with service provided and manufactured products. Earning revenue is directly related to increasing the sales volume. Therefore, today, companies aim to increase their productivity in order for a higher amount of output per unit time and especially increase their sales level, by integrating digital tools into their processes.

Maintenance Time: The short maintenance time in the aviation MRO industry is directly related to commercial success. The less time an aircraft spends in the hangar, the more it will be able to operate in flight activities, which means more revenue for airline companies and so more to be preferred for MRO companies.

Occupational Health & Safety: The aviation MRO sector is one of the sectors in the dangerous line of business category. For this reason, any activity that will increase the occupational health and safety of employees means positive gain in every aspect.

Business Quality: The quality of work in aviation maintenance and repair is one of the crucial factors affecting the commercial preference of the company, as well as directly affecting airworthiness and flight safety. Digitalization makes a great contribution to both the quality of processes, and the monitoring and control of quality.

Reputation: A large number of commercial enterprises operate in the aviation MRO sector around the world. In this sector where competition is high, customers tend to prefer companies that have proven themselves while making their choices. This means that

there is a greater tendency towards companies that carry their processes forward from the processes of other companies.

Applicability: Each step of aviation activities has been determined by national and international aviation authorities. For this reason, any changes that may occur in the processes should be in accordance with the determined rules and regulations. For these reasons, companies cannot act very flexibly in process and procedure changes. A process may not have a work stream suitable for the change transformation movement or a change may not be feasible financially for the process.

Table 6.1: The criteria considered when determining the field of usage of AI tech.

No	Code	Criteria Name	Impact
1	C1	Airworthiness	Benefit
2	C2	Flight Safety	Benefit
3	C3	Customer Satisfaction	Benefit
4	C4	Employee Acceptance	Benefit
5	C5	Maintenance Cost	Cost
6	C6	Revenue Growth	Benefit
7	C7	Maintenance Time	Cost
8	C8	Occupational Health & Safety	Benefit
9	C9	Business Quality	Benefit
10	C10	Reputation	Benefit
11	C11	Applicability	Benefit

6.2. Implementing of the AHP Method to Weight Criteria

Criteria weighting was determined by the AHP (analytical hierarchy process) method in this study. First of all, the AHP method is explained theoretically in, and the steps will be shown in Section 6.2.1, and then these steps are going to be applied on the case in Section 6.2.2.

6.2.1. AHP (Analytical Hierarchy Process) Method

The Analytical Hierarchy Process (AHP) was first introduced by Myers and Alpet in 1968 and was developed by Saaty in 1977 as a usable method for solving decision-making problems (Oktafianto et al., 2018); (Kasap & Subaşı, 2017). AHP is a MCDM method that can evaluate quantitative and qualitative criteria in decision-making, can include the preferences, experiences, intuitions, knowledge, judgments, and thoughts of the group or individual in the decision process, and enables complex problems to be solved by considering them in a hierarchical structure. The decision maker can include both objective and subjective thoughts in the decision process. Therefore, this situation provides the decision maker with the opportunity to recognize their own decision-making mechanisms. The calculation procedure of the AHP method for a MCDM problem with a finite set A of m alternatives and n evaluation criteria are performed with the following steps (Vargas et al., 2010):

Step 1: Creating the binary comparison matrix: The first step of the AHP method is to create the binary comparison matrix, in which the superiority of the criteria to each other is calculated. In evaluation phase, decision makers were asked to score the criterion comparison from 1 to 9, with 1 being the lowest and 9 the highest value of importance (Saaty, 2004).

$$C = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nm} \end{bmatrix} \quad (6.1)$$

where a_{ij} represents the pairwise comparison value of the i^{th} criterion and the j^{th} criterion.

Table 6.2: Comparison scale (Saaty, 2004)

Rating	Value Definition
1	Equal importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance

6	Strong plus
7	Very strong or demonstrated importance
8	Very, very strong
9	Extreme importance

Step 2: Normalization of the matrix and calculation of criteria weights: After the binary comparison matrix is created, the next step is the normalization of the matrix. The related weight is calculated with normalized values by the Equation (6.2):

$$W_i = \frac{1}{n} \sum_{j=1}^n \frac{a_{ij}}{\sum_{j=1}^n a_{ij}} \quad (6.2)$$

Step 3: Calculation of the consistency rate: To calculate consistency of the data, the first step is to calculate the eigenvalues of each criterion via the following equation:

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^n \frac{(AW)_i}{W_i} \quad (6.3)$$

After calculation of the eigenvalues, the consistency index is then calculated via the Equation (6.4);

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (6.4)$$

where n is the total number of criteria, i.e., 11.

After calculating the related values, the consistency rate needs to be calculated to investigate whether the decision makers' assessments are consistent or not via the following equation:

$$CR = \frac{CI}{RI} \quad (6.5)$$

where CI (Eq. 6.4) and RI (Table 6.3) are consistency index and random consistency

index, respectively. The consistency rate value must be less than 0.10 for a consistent data set.

Table 6.3: Random Consistency Index (Saaty, 1980)

n	3	4	5	6	7	8	9	10	11	12	13	14	15
RCI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

6.2.2. Determination of Criteria Weights via AHP Method

The alternative application areas and the criteria to be considered when decision making on processes have been revealed in Section 5 and 6.1, respectively. In this study, the opinions of 11 experts who have been working as managers, engineers, business analysts and software developers in the MRO sector for a long time were consulted as decision makers and their evaluations were taken.

Step 1: Creating the binary comparison matrix: The binary comparison matrix created by taking the averages of the evaluations of the experts is given in Table 6.4.

Table 6.4: Binary Comparison Matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C1	1	1	6	7	8	7	8	2	8	6	9
C2	1	1	7	9	8	6	9	3	4	8	8
C3	0.167	0.143	1	2	2	0.5	2	0.2	2	1	4
C4	0.143	0.111	0.5	1	0.333	0.25	0.333	0.5	4	0.5	4
C5	0.125	0.125	0.5	3	1	0.333	2	0.25	2	2	6
C6	0.143	0.167	2	4	3	1	3	0.25	4	1	7
C7	0.125	0.111	0.5	3	0.5	0.333	1	0.125	1	0.25	5
C8	0.5	0.333	5	2	4	4	8	1	6	7	9
C9	0.125	0.25	0.5	0.25	0.5	0.25	1	0.167	1	0.5	3
C10	0.167	0.125	1	2	0.5	1	4	0.143	2	1	7
C11	0.111	0.125	0.25	0.25	0.167	0.143	0.2	0.111	0.333	0.143	1

Step 2: Normalization of the matrix: Normalized version of Binary Comparison Matrix which is calculated using Equation (6.2) is given in Table 6.5.

Table 6.5: Normalized Binary Comparison Matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C1	0.28	0.29	0.25	0.21	0.29	0.34	0.21	0.26	0.23	0.22	0.14
C2	0.28	0.29	0.29	0.27	0.29	0.29	0.23	0.39	0.12	0.29	0.13
C3	0.05	0.04	0.04	0.06	0.07	0.02	0.05	0.03	0.06	0.04	0.06
C4	0.04	0.03	0.02	0.03	0.01	0.01	0.01	0.06	0.12	0.02	0.06
C5	0.03	0.04	0.02	0.09	0.04	0.02	0.05	0.03	0.06	0.07	0.10
C6	0.04	0.05	0.08	0.12	0.11	0.05	0.08	0.03	0.12	0.04	0.11
C7	0.03	0.03	0.02	0.09	0.02	0.02	0.03	0.02	0.03	0.01	0.08
C8	0.14	0.10	0.21	0.06	0.14	0.19	0.21	0.13	0.17	0.26	0.14
C9	0.03	0.07	0.02	0.01	0.02	0.01	0.03	0.02	0.03	0.02	0.05
C10	0.05	0.04	0.04	0.06	0.02	0.05	0.10	0.02	0.06	0.04	0.11
C11	0.03	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02

Step 3: Calculation of consistency rate: After the weighting of the criteria was found, the calculations for the consistency of the criteria evaluation values were made using Equations (6.3), (6.4) and (6.5). As a result of this, the following values were obtained;

- $\lambda_{max} = 12.46$
- $CI = 0.146$
- $CR = 9.66\%$

and it was observed that the consistency ratio was 0.097 and less than 0.10, which means the data is consistent.

As a result of the evaluations whose data set is confirmed to be consistent, it is determined that the weighting of the criteria to be considered for the most appropriate process selection is as in Table 6.6.

Table 6.6: Criteria weights of process selection

Rank	Criteria Name	Weight (%)
1	Flight Safety	25.92
2	Airworthiness	24.57
3	Occupational Health & Safety	15.86
4	Revenue Growth	7.44
5	Reputation	5.25
6	Maintenance Cost	4.94
7	Customer Satisfaction	4.72
8	Employee Satisfaction	3.79
9	Maintenance Time	3.37
10	Business Quality	2.79
11	Applicability	1.34

6.3. Selection of the Application Area by Using WEDBA Method

Evaluating alternatives will be made by the WEDBA method. Firstly, the WEDBA method is explained theoretically, and the steps are shown in Section 6.3.1, and then these steps will be applied on the case in Section 6.3.2.

6.3.1. WEDBA (Weighted Euclidean Distance Based Approach) Method

The WEDBA method, which is based on the mathematical concept of Euclidean, aims to prioritize alternatives by their distances from the least (anti-ideal point) and the most (ideal point) favorable situation, respectively (Rao & Singh, 2011). According to Rao et al. (2012), who introduced the WEDBA method to the literature, the application procedure of the method proceeds as follows:

Step 1: Creation of decision matrix: First of all, m alternatives are evaluated against n criteria, and a decision matrix D is created by determining the y_{ij} performance value of each alternative according to each criterion (Equation 6.6). If a subjective evaluation is to be made in this step, the scores in Table 6.2 can be used.

$$D = \begin{bmatrix} y_{11} & \cdots & y_{1n} \\ \vdots & \ddots & \vdots \\ y_{m1} & \cdots & y_{mn} \end{bmatrix} \quad (6.6)$$

Step 2: Standardization of the decision matrix: After the decision matrix is created, the next step is the standardization of the matrix. The standardization of the matrix (Equation 6.6) is established by the contribution of the normalized values (Equation 6.8): beneficial attribute and non-beneficial attribute equations as shown in Equation (6.9) and Equation (6.10), respectively.

$$D' = \begin{bmatrix} Z_{11} & \cdots & Z_{1n} \\ \vdots & \ddots & \vdots \\ Z_{m1} & \cdots & Z_{mn} \end{bmatrix} \quad (6.7)$$

where

$$Z_{ij} = \frac{x_{ij} - \mu_j}{\sigma_j} \quad (6.8)$$

$$x_{ij} = \frac{y_{ij}}{\max_j(y_{ij})} \text{ if } j^{\text{th}} \text{ attribute is beneficial} \quad (6.9)$$

$$x_{ij} = \frac{\min_j(y_{ij})}{y_{ij}} \text{ if } j^{\text{th}} \text{ attribute is non – beneficial} \quad (6.10)$$

$$\mu_j = \frac{1}{m} \sum_{i=1}^m x_{ij} \quad (6.11)$$

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^m (x_{ij} - \mu_j)^2}{m}} \quad (6.12)$$

Z_{ij} is the normalized value of x_{ij} , μ_j and σ_j is the expected/mean value for j^{th} attribute and the standard deviation for the attribute j , respectively (Kumar and Garg, 2010).

Step 3: Determining the ideal and anti-ideal point: Ideal values are obtained using Equation (6.13) and anti-ideal values using Equation (6.14):

$$y_{ij}^+ = \max(y_{ij}) \quad (6.13)$$

$$y_{ij}^- = \min(y_{ij}) \quad (6.14)$$

Step 4: Calculation of weighted Euclidean distance, index score and ranking: Weighted Euclidean Distances for each alternative are obtained using Equations (6.15) and (6.16), respectively.

$$WED_i^+ = \sqrt{\sum_{j=1}^n \{w_j (y_{ij} - y_{ij}^+)\}^2} \quad (6.15)$$

$$WED_i^- = \sqrt{\sum_{j=1}^n \{w_j (y_{ij} - y_{ij}^-)\}^2} \quad (6.16)$$

where w_j is the weight of each criterion, $j = 1, 2, 3, \dots, n$.

Then, using Equation (6.17) with these values, index scores of each alternative are obtained.

$$IS_i = \frac{WED_i^-}{WED_i^- + WED_i^+} \quad (6.17)$$

The alternative with the highest index value IS_i is the best alternative.

6.3.2. Implementation of WEDBA to Prioritize Usage of Fields

The WEDBA method, the application steps of which were explained in the previous Section 6.3.1, is applied by applying in consideration of 11 criteria for eight potential alternatives to which AI technology can be applied. The results and data of each step are given below.

Step 1: Creation of decision matrix: The experts (as decision makers) scored each alternative from 1 to 9 according to the scores in Table 6.2 for each criterion, and the average of these evaluations was calculated to form the decision matrix shown in Table 6.7 below. It is note that “maintenance cost (C5)” and “maintenance time (C7)” are non-benefit criteria for these alternatives.

Table 6.7: Decision Matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
A1	8	7	4	8	8	1	7	1	6	3	8
A2	3	7	3	9	9	1	6	6	7	8	2
A3	6	9	7	8	9	4	7	7	7	8	2
A4	4	4	2	9	7	2	5	1	9	4	4
A5	9	3	8	8	3	9	4	1	4	8	8
A6	8	9	9	2	5	8	4	2	2	9	6
A7	7	5	9	8	4	9	1	7	8	7	8
A8	7	7	8	6	8	3	4	4	8	6	4

Step 2: Standardization of the decision matrix: The standardized version of the decision matrix using Equations (6.7), (6.8), (6.9), (6.10), (6.11) and (6.12) is shown in Table 6.8 below.

Table 6.8: The standardized decision matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
A1	0.77	0.30	-0.85	0.35	-0.66	-1.11	-0.59	-1.03	-0.17	-1.82	1.13
A2	-1.81	0.30	-1.23	0.81	-0.84	-1.11	-0.50	0.93	0.29	0.69	-1.33

A3	-0.26	1.28	0.28	0.35	-0.84	-0.19	-0.59	1.33	0.29	0.69	-1.33
A4	-1.29	-1.15	-1.61	0.81	-0.42	-0.80	-0.37	-1.03	1.21	-1.32	-0.51
A5	1.29	-1.64	0.66	0.35	2.10	1.34	-0.19	-1.03	-1.09	0.69	1.13
A6	0.77	1.28	1.04	-2.42	0.33	1.03	-0.19	-0.64	-2.01	1.19	0.31
A7	0.26	-0.67	1.04	0.35	1.00	1.34	2.61	1.33	0.75	0.19	1.13
A8	0.26	0.30	0.66	-0.58	-0.66	-0.50	-0.19	0.15	0.75	-0.31	-0.51

Step 3: Determining the ideal and anti-ideal point: With reference to Equations (6.13) and (6.14), the ideal and anti-ideal points are as shown below;

$$y_{ij}^+ = \{1.29; 1.28; 1.04; 0.81; 2.10; 1.34; 2.61; 1.33; 1.21; 1.19; 1.13\}$$

$$y_{ij}^- = \{-1.81; -1.64; -1.61; -2.42; -0.84; -1.11; -0.59; -1.03; -2.01; -1.82; -1.33\}$$

Step 4: Calculation of weighted Euclidean distance, index score and ranking: Criterion weighting was carried out by the AHP method as described under Section 6.2.1. Euclidean distance is calculated using Equations (6.15) and (6.16), index score is calculated using Equation (6.17), and then alternatives are ranked as shown Table 6.9 below:

Table 6.9: The results of WEDBA implementation

	WED_i^+	WED_i^-	IS_i	Rank
Document Management	0.563	0.683	0.548	5
Augmented Reality	0.852	0.776	0.477	6
Anomaly Detection	0.441	0.688	0.609	2
Recruitment	1.012	0.803	0.442	8
Supply Chain Optimization	0.852	0.772	0.476	7
Predictive & Preventive Maintenance	0.392	0.670	0.631	1
Maintenance Scheduling	0.570	0.718	0.557	4
Automated Quality Control	0.468	0.687	0.595	3

According to the results in Table 6.9, the rank of alternative usage fields in MRO processes of AI technology is as follows; Predictive & Preventive Maintenance, Anomaly Detection, Automated Quality Control, Document Management, Maintenance Scheduling, Supply Chain Optimization, Augmented Reality, Recruitment. It is recommended that an MRO company will first turn to a predictive & preventive maintenance area from AI technology applications. Anomaly detection field with a very close score has emerged as another innovative area that can improve aviation MRO processes at a significant level. In the light of these evaluations, artificial intelligence integration into the recruitment process is determined as the latest area to invest.



7. USING MCDM METHOD on WHICH AI TOOL to USE FOR PREDICTIVE & PREVENTIVE MAINTENANCE

Many companies, large and small, produce software solutions in the field of predictive & preventive maintenance for the aviation MRO sector. The OEMs and the MRO companies, especially leading the industry, spend a lot of time on this issue. In addition, several start-up and technology companies are also closely interested in the subject. Although big data and analytics-based studies are not new in the aviation MRO industry, products for predictive & preventive maintenance have been available for approximately the last 5 years (Klisauskaite, 2021).

As a result of MCDM study carried out in the heading of 6, it is revealed that the first priority process for the use of AI in the aviation MRO sector is predictive & preventive maintenance. Accordingly, 11 different software tools³ that can be used in this field for the aviation MRO sector was determined by conducting market research, and the vendors of the AI solutions are detailed as shown Table 7.1.

Table 7.1: Features of Alternatives

Code	Alternative Name	Sector	Business Detail	Business Size
A1	Alternative-1	Technology	IT Solutions	Small
A2	Alternative-2	Technology	IT Solutions	Medium
A3	Alternative-3	Aviation	Airline	Large

³ Because of commercial information confidentiality, the company and the software names are kept hidden throughout the study.

A4	Alternative-4	Aviation	OEM, aircraft & part manufacturer	Large
A5	Alternative-5	Aviation	OEM, aircraft & part manufacturer	Large
A6	Alternative-6	Aviation	Airline	Large
A7	Alternative-7	Aviation	Aviation Solutions	Large
A8	Alternative-8	Production	OEM, part manufacturer	Large
A9	Alternative-9	Technology	Aviation IT Solutions	Medium
A10	Alternative-10	Technology	Maintenance IT Solutions	Small
A11	Alternative-11	Technology	IT Solutions	Large

An MCDM study is conducted in the Sections of 7.1 and 7.2 in order to decide the most appropriate one for the process among these 11 tools that differ from each other in many aspects such as the technology used, features/capabilities, project cost, scope, after-sales services, and process requirements, etc. The weights of the cost-benefit criteria determined in the Section 7.1 were designated via the AHP method, and the WEDBA method is used as the MCDM method in the Section 7.2 for this study.

7.1. Defining Criteria for Selection of AI Tool among Alternatives to Use in Predictive and Preventive Maintenance

Based on the MCDM studies in the literature related to software selection (Kazancıoğlu and Burmaoğlu, 2013; Gürbüz vd., 2012), and the evaluations of experts in IT sector, the alternatives were evaluated according to the following criteria while determining the most suitable AI tool for the predictive & preventive maintenance process: Data Security (C1), Compatibility with Existing IT Systems (C2), Project Cost (C3), System Installation Time (C4), Degree of risk (C5), User-friendliness (C6), Service and Support (C7), Flexibility (C8), Functions/features (C9), Reliability (C10), Vendor Reputation (C11), Product Viability (C12), and Technology Preferences (C13).

Data Security: Data security is very important in aviation MRO operations. In digital processes, while the data is shared securely and transparently with stakeholders, it should also be protected against malware and should not fall into the hands of malicious individuals. Maintenance and repair data are primary records for providing aircraft airworthiness and ensuring flight safety. Therefore, its loss, manipulation or inaccessibility may result in serious consequences.

Compatibility with Existing IT Systems: An MRO activity uses many software programs that are integrated with each other. A new software project is expected to be compatible with the current database, framework, technology, etc. of the company IT system to integrate into. Otherwise, it requires serious effort and time for its implementation and integration.

Project Cost: Predictive and preventive maintenance is a costly software business that MRO companies can be concerned about. It is expected that the budget allocated for the investment will be returned as a benefit to the company in a short time. While performing the cost analysis of the investment, its contribution to the whole operation is compared by taking into account the installation, maintenance, support, and renewal costs. Although costly options may offer extra features, it will be difficult to prefer in the first place.

System Installation Time: After the software selection is made and the agreement is reached, the shorter the installation and integration time of the relevant software, the higher the satisfaction.

Degree of risk: Every project carries some risks, such as failure of the project or producing inaccurate results, data security weaknesses due to the use of sensitive data, and system crash. It is necessary to carry out a comprehensive risk analysis against these risks, to take precautionary measures against possible problems and to create disaster scenarios for actions to be taken in case of any disruption. The demand for projects with high-risk coefficient is low.

User-friendliness: A software that does not frustrate the staff while using it, which will enable the requested operation to be performed in the easiest way with simplified menus and screens, and that even non-technical or non-expert personnel can straightforwardly reach the sections they need is a great advantage for the companies.

Service and Support: One of the key factors to consider in a software preference is the service and support activities provided by the vendor throughout its lifetime. In order for the software to be used for a long time and the benefit to be obtained from the software to be at the maximum level, it is necessary to take quick action against the problems that occur, to perform the maintenance adequately and on time, and to keep up to date the software.

Flexibility: During the use of the software, business processes may change, differences may occur in existing IT systems, and new demands and needs may arise. The preferred software should be flexible to respond to such changeable situations. Otherwise, it will not be able to meet the need after a while and will cause it to fall into disuse in a short time.

Functions/features: When choosing a preventive & predictive maintenance software program, it is important for aviation MRO companies to meet their unique and changeable needs, especially to provide a wide range of flexible solutions in business intelligence & reporting, and to support use on different devices.

Reliability: Software reliability is the likelihood that the software will operate without failure for a period of time set in a specified environment (Musa et al., 1990). Reliability reveals the quality level of a software from the customer's eye.

Vendor Reputation: The number of companies that the vendor serves in the aviation MRO sector, the size of these companies, and their satisfaction and feedback from its products are important parameters in choosing the supplier and its product.

Product Viability: As well as the reputation of the vendor in the market, the fact that the product is recommended, liked, and widely used by the MRO companies, is an indication that the software can be used for a long time and that the vendor's support for the software will continue for a long time. The high signs of long-term viability of the product increase its preference by the customers.

Technology Preferences: The fact that the technology and software language used in the product is accepted in the software world and has a high usage rate will increase the trust and preferability of the software in terms of customers.

7.2. Weighting Criteria via AHP Method

The alternative predictive & preventive maintenance tool and the criteria to be considered when decision making on processes have been revealed heretofore. Criteria weighting is determined by the AHP method and the evaluations of experts in the sector were consulted again. All the steps mentioned under Section 6.2 are followed one by one and the result is reached:

Step 1: Creating the binary comparison matrix: The binary comparison matrix originated from taking the averages of the evaluations of the experts is given in Table 7.2.

Table 7.2: Binary Comparison Matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
C1	1	4	5	8	1	7	6	7	7	2	8	3	8
C2	0.25	1	0.333	5	0.333	5	3	3	3	1	6	2	3
C3	0.2	3	1	8	0.2	6	4	3	4	2	6	2	4
C4	0.125	0.2	0.125	1	0.125	0.167	0.333	0.5	0.143	0.125	0.5	0.167	0.333
C5	1	3	5	8	1	7	6	6	5	2	5	3	4
C6	0.143	0.2	0.167	6	0.143	1	0.5	0.5	0.5	0.167	1	0.143	0.5
C7	0.167	0.333	0.25	3	0.167	2	1	0.5	0.5	0.2	0.5	0.25	0.333
C8	0.143	0.333	0.333	2	0.167	2	2	1	0.333	0.167	4	0.143	2
C9	0.143	0.333	0.25	7	0.2	2	2	3	1	0.167	6	0.143	2
C10	0.5	1	0.5	8	0.5	6	5	6	6	1	4	2	5

C11	0.125	0.167	0.167	2	0.2	1	2	0.25	0.167	0.25	1	0.333	2
C12	0.333	0.5	0.5	6	0.333	7	4	7	7	0.5	3	1	5
C13	0.125	0.333	0.25	3	0.25	2	3	0.5	0.5	0.2	0.5	0.2	1

Step 2: Normalization of the matrix: Normalized version of Binary Comparison Matrix which is calculated using Equation (6.2) is given in Table 7.3.

Table 7.3: Normalized Binary Comparison Matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
C1	0.24	0.28	0.36	0.12	0.22	0.15	0.15	0.18	0.20	0.20	0.18	0.21	0.22
C2	0.06	0.07	0.02	0.07	0.07	0.10	0.08	0.08	0.09	0.10	0.13	0.14	0.08
C3	0.05	0.21	0.07	0.12	0.04	0.12	0.10	0.08	0.11	0.20	0.13	0.14	0.11
C4	0.03	0.01	0.01	0.01	0.03	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01
C5	0.24	0.21	0.36	0.12	0.22	0.15	0.15	0.16	0.14	0.20	0.11	0.21	0.11
C6	0.03	0.01	0.01	0.09	0.03	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.01
C7	0.04	0.02	0.02	0.04	0.04	0.04	0.03	0.01	0.01	0.02	0.01	0.02	0.01
C8	0.03	0.02	0.02	0.03	0.04	0.04	0.05	0.03	0.01	0.02	0.09	0.01	0.05
C9	0.03	0.02	0.02	0.10	0.04	0.04	0.05	0.08	0.03	0.02	0.13	0.01	0.05
C10	0.12	0.07	0.04	0.12	0.11	0.12	0.13	0.16	0.17	0.10	0.09	0.14	0.13
C11	0.03	0.01	0.01	0.03	0.04	0.02	0.05	0.01	0.00	0.03	0.02	0.02	0.05
C12	0.08	0.03	0.04	0.09	0.07	0.15	0.10	0.18	0.20	0.05	0.07	0.07	0.13
C13	0.03	0.02	0.02	0.04	0.05	0.04	0.08	0.01	0.01	0.02	0.01	0.01	0.03

Step 3: Calculation of consistency rate: After the weighting of the criteria was found, the calculations for the consistency of the criteria evaluation values were made using Equations (6.3), (6.4) and (6.5). As a result of this, the following values were obtained;

- $\lambda_{max} = 17.75$
- $CI = 0.146$
- $CR = 9.37\%$

and it was observed that the consistency ratio was 0.094 and less than 0.10, which means the data is consistent.

As a result of the evaluations whose data set is confirmed to be consistent, it is determined that the weighting of the criteria to be considered for the most appropriate process selection is as in Table 7.4.

Table 7.4: Criteria weights of process selection

Rank	Criteria Name	Weight (%)
1	Data Security	24.50
2	Degree of risk	21.54
3	Reliability	13.60
4	Project Cost	13.57
5	Product Viability	11.48
6	Compatibility with Existing IT Systems	9.98
7	Functions/features	5.77
8	Flexibility	4.04
9	Technology Preferences	3.53
10	Vendor Reputation	3.04
11	Service and Support	2.85
12	User-friendliness	2.76
13	System Installation Time	1.53

7.3. Implementing WEDBA to Prioritize Alternative AI Tools

The WEDBA method, the application steps of which were explained and detailed in Section 6.3.1, is applied step by step by applying in consideration of 13 criteria for 11 potential alternatives to which AI technology can be applied. The results and data of each step are given below.

Step 1: Creation of decision matrix: The experts (as decision makers) scored each alternative from 1 to 9 according to the scores in table 6.2 for each criterion, and the average of these evaluations was calculated to form the decision matrix shown in Table

7.5 below. It is note that “project cost (C3)”, “system installation time (C4)” and “degree of risk (C5)” are non-benefit criteria for these alternatives.

Table 7.5: Decision Matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
A1	5	6	1	4	7	8	3	8	7	2	1	3	9
A2	6	5	2	3	6	7	3	6	8	3	2	3	9
A3	7	9	9	7	3	8	8	5	8	8	9	8	6
A4	7	7	8	8	3	6	7	4	7	7	9	8	6
A5	8	7	8	7	3	8	7	4	8	8	9	8	5
A6	7	6	9	6	3	7	8	6	9	8	9	9	7
A7	8	7	7	5	5	8	7	7	7	6	6	7	8
A8	4	6	7	8	6	3	5	3	3	7	9	8	6
A9	7	9	5	5	6	7	7	8	6	6	4	6	8
A10	4	8	3	9	6	4	5	6	5	6	2	6	7
A11	8	2	4	8	7	5	6	3	8	9	9	9	9

Step 2: Standardization of the decision matrix: The standardized version of the decision matrix using Equations (6.7), (6.8), (6.9), (6.10), (6.11) and (6.12) is shown in Table 7.6 below.

Table 7.6: The standardized decision matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
A1	-1.01	-0.29	2.83	1.17	-1.01	0.92	-1.76	1.48	0.06	-2.12	-1.64	-1.87	1.28
A2	-0.32	-0.82	0.87	2.46	-0.72	0.33	-1.76	0.32	0.67	-1.64	-1.33	-1.87	1.28
A3	0.38	1.31	-0.65	-0.49	1.30	0.92	1.17	-0.26	0.67	0.80	0.85	0.58	-0.94
A4	0.38	0.24	-0.59	-0.77	1.30	-0.27	0.59	-0.84	0.06	0.31	0.85	0.58	-0.94
A5	1.08	0.24	-0.59	-0.49	1.30	0.92	0.59	-0.84	0.67	0.80	0.85	0.58	-1.68
A6	0.38	-0.29	-0.65	-0.12	1.30	0.33	1.17	0.32	1.29	0.80	0.85	1.07	-0.20
A7	1.08	0.24	-0.52	0.39	-0.32	0.92	0.59	0.90	0.06	-0.18	-0.08	0.09	0.54

A8	-1.71	-0.29	-0.52	-0.77	-0.72	-2.07	-0.59	-1.42	-2.41	0.31	0.85	0.58	-0.94
A9	0.38	1.31	-0.30	0.39	-0.72	0.33	0.59	1.48	-0.56	-0.18	-0.71	-0.40	0.54
A10	-1.71	0.78	0.22	-0.99	-0.72	-1.47	-0.59	0.32	-1.18	-0.18	-1.33	-0.40	-0.20
A11	-1.01	-0.29	2.83	1.17	-1.01	0.92	-1.76	1.48	0.06	-2.12	-1.64	-1.87	1.28

Step 3: Determining the ideal and anti-ideal point: Based on the Equations (6.13) and (6.14), the ideal and anti-ideal points are as shown below;

$$y_{ij}^+ = \{1.08; 1.31; 2.83; 2.46; 1.30; 0.92; 1.17; 1.48; 1.29; 1.28; 0.85; 1.07; 1.28\}$$

$$y_{ij}^- = \{-1.71; -2.42; -0.65; -0.99; -1.01; -2.07; -1.76; -1.42; -2.41; -2.12; -1.64; -1.87; -1.68\}$$

Step 4: Calculation of weighted Euclidean distance, index score and ranking: Criterion weighting was carried out by the AHP method as described under Section 6.2.1. Euclidean distance is calculated using Equations (6.15) and (6.16), and index score is calculated using Equation (6.17), and then alternatives are ranked as shown Table 7.7 below:

Table 7.7: The results of WEDBA implementation

	WED_i^+	WED_i^-	IS_i	Rank
Alternative-1	0.939	0.591	0.386	8
Alternative-2	0.842	0.497	0.371	9
Alternative-3	0.523	0.969	0.649	2
Alternative-4	0.548	0.896	0.620	4
Alternative-5	0.508	1.034	0.671	1
Alternative-6	0.537	0.947	0.638	3
Alternative-7	0.633	0.853	0.574	5
Alternative-8	0.993	0.495	0.333	11
Alternative-9	0.695	0.739	0.515	7
Alternative-10	0.943	0.482	0.338	10
Alternative-11	0.752	0.922	0.551	6

According to the results in the Table 7.7, the order of suitability of the alternative tools for the predictive maintenance application in aviation MRO sector is as follows: 5 > 3 > 6 > 4 > 7 > 11 > 9 > 1 > 2 > 10 > 8. Alternative-5 is a software program offered to the aviation industry by a large OEM company that produces aircraft and aircraft parts. This program includes many indicators and components not only for predictive and preventive maintenance using AI technology, but also for improving the general health status of an aircraft, and monitoring and increasing its performance. Even though Alternative-5 is the best alternative, Alternative-3, Alternative-6, and Alternative-4 also get a high score and are positioned close to Alternative-5. These alternatives are AI-driven MRO solution software programs offered by large global companies that shape the aviation industry.

8. DISCUSSIONS

The main purpose of this thesis study is to contribute to the prioritization and decision-making process for the applications of artificial intelligence applications in the aviation MRO sector. On the other hand, it also aims to create a general impression of how this technology, which is one of the innovative trends, can be integrated into which process in this sector. For these purposes, all application areas of AI technology and all MRO processes have been comprehensively discussed in the study.

When the researches in the literature and the trends of the companies operating in the sector are examined, eight main fields of application where artificial intelligence technology can be used in the aviation MRO sector or where enterprises are made in these areas came to the fore. One of the key points of this thesis is that there is a study on the lack of literature on which criteria should be evaluated while choosing a software project in the aviation MRO sector. For this process, 11 criteria were determined to be considered. The evaluation of the criteria has been achieved with 11 participants who work in the aviation MRO sector and have sufficient technical know-how and knowledge of the dynamics of the sector as to be a decision maker. Since subjective evaluations have been consulted, criteria weighting has been done by the AHP method. As a result of this study, the two most important criteria (flight safety and airworthiness) for air transportation reached a total weight of almost 50 percent. This means that a software project to be selected is expected to have a significant contribution to flight safety and airworthiness. Then, taking into account of the weights of these criteria, the eight usage areas determined by the WEDBA method were prioritized. Although the WEDBA method is not a very new concept, it is a method that has a limited number of applications in literature. However, it was considered a suitable method for this study, that is why it is open to both objective and subjective evaluation, is easy to apply and gives successful results in terms of performance. As a result of this MCDM study, it was concluded that “predictive & preventive maintenance” should be integrated first to MRO processes.

Moreover, the areas of “anomaly detection” and “automated quality control” have also received very close scores. This result shows that the MCDM study has resulted consistently, since all three areas are ones that are directly related to “flight safety” and “airworthiness”.

After the initial phase of the thesis was determined as predictive maintenance, the next stage was the software solutions research for this area. The software tools offered by 11 companies with different business scales for this area were examined. The AHP method has been used again for the MCDM study to determine which of these software tools will be more appropriate. 13 criteria were determined for the subjective evaluations of the experts. Among these criteria, “data security” and “degree of risk” are the highest weights. Again, the WEDBA method was also applied for the assessment of the 11 areas identified, as in the previous stage. As a result of this study, it was concluded that “Alternative-5” developed by an aircraft manufacturer and part supplier OEM company, which has a very close score with “Alternative-3” developed by an airline company, is the most appropriate software solution. This result can be interpreted as an expectable situation since these software tools towards predictive and preventive maintenance field are developed by those companies which have been operating in the aviation industry for many years.

In this thesis, where innovative studies are carried out at many points for the literature on the aviation MRO sector, it is obvious that there are some points that need to be improved. Those can be considered as the leading topics that should be developed for future studies: the evaluations were mostly based on subjective opinion instead of objective data while applying MCDM methods, the sample size of evaluator experts was limited, the results obtained by different MCDM methods were not compared and sensitivity analysis were not performed. The number of benefit criteria can be increased for both studies. The studies handled in two different steps may be included in one integrated study with a different MCDM selected. Besides, in further research, the financial performance of the project can be measured by making a feasibility analysis and possible problems can be revealed with a comprehensive risk analysis.

9. CONCLUSION

Innovative approaches offer groundbreaking solutions to facilitate processes in both business and normal life. In this period, when keeping up with the needs of the era is vital in a competitive environment, it is crucial to improve operational processes for the aviation industry, which is growing rapidly day by day, new actors are involved in the industry, and the profit margin is very low. At this point, the trend innovation approaches, such as block chains, the Internet of Things, artificial intelligence, can be properly integrated into the appropriate business processes, leading to a step ahead of other competitors in the industry.

In this thesis, a series of research and evaluation studies had been carried out on the use of artificial intelligence technology in the aviation MRO sector. Potential fields and trends in which this technology can be used in this sector have been researched, and it has been tried to obtain inferences that will support the decision-making process to be made before the implementation of these applications in real life. This thesis consists of four main stages, with the goal of finding the right artificial intelligence application area and then the best software solution for this area. The first stage provides an overview of artificial intelligence technology, followed by MRO processes. In the last two target-oriented stages, respectively, it is tried to determine the most suitable AI application area for aviation MRO processes and then the most suitable software tool for this area via MCDM methods.

The eight potential AI application areas that can be integrated into the processes in the aviation MRO sector have been identified by literature review. In order to find the most appropriate one among them, 11 aviation-related criteria have been determined to be taken into account. These criteria are weighed by the AHP method. As a result of this study, it has been concluded that the most effective criteria that will affect the decision-making result are “flight safety” and “airworthiness”. Following this, the area of

“predictive and preventive maintenance” application, which is the most prioritized area among eight alternative application areas, was determined considering these criteria via WEDBA method. Afterwards, a market research was conducted for this area and 11 potential software solutions were examined. 13 criteria have been determined in order to find the most suitable software tools. These criteria were also weighted by the AHP method, and it was understood that the key criteria were “data security” and “degree of risk”. It was then used again by the WEDBA method to find the most suitable software tool for the predictive and preventive maintenance area. At the end of this process, it was found that the most suitable software tool for predictive and preventive maintenance was "Alternative-5". All MCDM applications were carried out by taking the opinion of 11 expert decision makers in the sector.

In the literature, there is no study that contextualizes artificial intelligence applications and MCDM methods for this sector that is why this thesis study has an original characteristic. For future research; the study can be supported with numerical data where objective evaluations can be made, the number of benefit criteria can be increased. The reliability of the results can be examined with different MCDM tools, or this two-step study, which is correlative with each other, can be studied under a single roof with a different MCDM method. For a possible project, the financial feasibility of the project can be evaluated with the feasibility analysis, and detailed analysis of the possible risks that may be experienced during the implementation of the project can be revealed with the risk analysis.

REFERENCES

- Amin, N., Yother, T., Johnson, M., & Rayz, J. (2022). Exploration of Natural Language Processing (NLP) Applications in Aviation. *The Collegiate Aviation Review International*, 40(1).
- Amirkolaii, K. N., Baboli, A., Shahzad, M. K., & Tonadre, R. (2017). Demand forecasting for irregular demands in business aircraft spare parts supply chains by using artificial intelligence (AI). *IFAC-PapersOnLine*, 50(1), 15221-15226.
- Apostolidis, A., & Stamoulis, K. P. (2021). An AI-based Digital Twin Case Study in the MRO Sector. *Transportation Research Procedia*, 56, 55-62.
- Apostolidis, A., Pelt, M., & Stamoulis, K. P. (2020, January). Aviation Data Analytics in MRO Operations: Prospects and Pitfalls. *In 2020 Annual Reliability and Maintainability Symposium (RAMS)* (pp. 1-7). IEEE.
- Bouarfa, S., Dođru, A., Arizar, R., Aydođan, R., & Serafıco, J. (2020). Towards Automated Aircraft Maintenance Inspection. A use case of detecting aircraft dents using Mask R-CNN. *In AIAA Scitech 2020 forum* (p. 0389).
- Chen, Z. H., & Juang, J. C. (2022). YOLOv4 Object Detection Model for Nondestructive Radiographic Testing in Aviation Maintenance Tasks. *AIAA Journal*, 60(1), 526-531.
- Cheng, T., Wen, P., & Li, Y. (2016, December). Research status of artificial neural network and its application assumption in aviation. *In 2016 12th International Conference on Computational Intelligence and Security (CIS)* (pp. 407-410). IEEE.
- Çankaya, D. (2020). Havacılıkta Yaygınlaşan Yapay Zeka, API ve Büyük Veri Temelli Çözümler. *Academic Perspective Procedia*, 3(1), 465-473.
- EASA: Roadmap, A. I. (2020). A human-centric approach to AI in aviation. *European Aviation Safety Agency*, 1.
- EFNMS, 2013. "MRO Definition". European Federation of National Maintenance Society. **URL:** <http://www.efnms.org/>

- EVERETT, Wash., May 29, 2013. **URL:** <https://boeing.mediaroom.com/2013-05-29-Boeing-Celebrates-Delivery-of-50th-747-8/>
- Fayek, H. M., Candon, M., Levinski, O., Koschel, S., & Marzocca, P. (2021, January). Deep learning airframe load prediction: A data-driven system for aircraft structural health management. *In AIAC 2021: 19th Australian International Aerospace Congress: 19th Australian International Aerospace Congress* (pp. 448-453). Engineers Australia.
- Garcia, A. B., Babiceanu, R. F., & Seker, R. (2021, April). Artificial Intelligence and Machine Learning Approaches For Aviation Cybersecurity: An Overview. *In 2021 Integrated Communications Navigation and Surveillance Conference (ICNS)* (pp. 1-8). IEEE.
- Gürbüz, T., Alptekin, S. E., & Alptekin, G. I. (2012). A hybrid MCDM methodology for ERP selection problem with interacting criteria. *Decision Support Systems*, 54(1), 206-214.
- GWR (2022). Aircraft MRO Market Size, Share & Trends Analysis Report By Service Type (Engine Overhaul, Airframe Maintenance), By Organization Type, By Aircraft Type, By Aircraft Generation, And Segment Forecasts, 2022 – 2030. Grand View Research. **URL:** <https://www.grandviewresearch.com/industryanalysis/aircraft-mro-market#/>
- Haenlein, M., & Kaplan, A. (2019). A brief history of artificial intelligence: On the past, present, and future of artificial intelligence. *California management review*, 61(4), 5-14.
- IATA (2020): Airline Maintenance Cost Commentary FY2019 Data. **URL:** https://www.iata.org/contentassets/bf8ca67c8bcd4358b3d004b0d6d0916f/fy2019-mctg-re-port_public.pdf/
- IATA (2021): Airline Maintenance Cost Executive Commentary FY2020 Data. **URL:** https://www.iata.org/contentassets/bf8ca67c8bcd4358b3d004b0d6d0916f/fy2020-mctg-report_public.pdf/
- Johnson, W. B. (1990, October). Advanced technology for aviation maintenance training: An industry status report and development plan. *In Proceedings of the Human Factors Society Annual Meeting* (Vol. 34, No. 16, pp. 1171-1175). Sage CA: Los Angeles, CA: SAGE Publications.

- Kaparthi, S., & Bumblauskas, D. (2020). Designing predictive maintenance systems using decision tree-based machine learning techniques. *International Journal of Quality & Reliability Management*.
- Kasap, Y., & Subaşı, E. (2017). Risk assessment of occupational groups working in open pit mining: Analytic Hierarchy Process. *Journal of Sustainable Mining*, 16(2), 38-46.
- Kazancoglu, Y., & Burmaoglu, S. (2013). ERP software selection with MCDM: application of TODIM method. *International Journal of Business Information Systems*, 13(4), 435-452.
- Khan, S. A., Chaabane, A., & Dweiri, F. T. (2018). Multi-criteria decision-making methods application in supply chain management: A systematic literature. *Multi-criteria methods and techniques applied to supply chain management*, 1.
- Kinnison, H. A. (2013). Aviation maintenance management. *McGraw-Hill Education*.
- Klisauskaite, V. (2021, July 19). Predictive aircraft maintenance: established practice or future focus? Aerotime Hub. **URL:** <https://www.aerotime.aero/articles/28331-predictive-aircraft-maintenance-MRO/>
- Kulida, E., & Lebedev, V. (2020, September). About the use of artificial intelligence methods in aviation. In *2020 13th International Conference "Management of large-scale system development" (MLSD)* (pp. 1-5). IEEE.
- Lufthansa Technik. Material Pooling: The benefit of sharing. **URL:** <https://www.lufthansa-technik.com/material-pooling/>
- Musa, J. D., Iannino, A., & Okumoto, K. (1990). Software reliability. *Advances in computers*, 30. 85-170.
- Ning, S., Sun, J., Liu, C., & Yi, Y. (2021). Applications of deep learning in big data analytics for aircraft complex system anomaly detection. *Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability*, 235(5), 923-940.
- Oktafianto, M. R., Al Akbar, Y. F., Zulkifli, S., & Wulandari, A. M. (2018). Dismissal working relationship using analytic hierarchy process method. *International Journal of Pure and Applied Mathematics*, 118(7), 177-184.
- Pelt, M., Apostolidis, A., de Boer, R. J., Borst, M., Broodbakker, J., Jansen, R., ... & Stamoulis, K. (2019). Data mining in MRO. *Amsterdam: Aviation Academy Research Programme*, Amsterdam University of Applied Sciences.

- PwC (2017). Sizing the prize: What's the real value of AI for your business and how can you capitalise? *London: PwC*.
- Rajkov, D. (2018). Blockchain for aircraft spare part management: Evaluating the robustness of the Maintenance, Repair and Overhaul business model.
- Rao, R. V., Singh, D., Bleicher, F., & Dorn, C. (2012). Weighted Euclidean distance-based approach as a multiple attribute decision making method for manufacturing situations. *International Journal of Multicriteria Decision Making*, 2(3), 225-240.
- Rao, R. V., & Singh, D. (2011). "Evaluating Flexible Manufacturing Systems Using Euclidean Distance Based Integrated Approach". *International Journal of Decision Sciences, Risk and Management*, 3(1-2): 32-53
- Rengasamy, D., Morvan, H. P., & Figueredo, G. P. (2018, November). Deep learning approaches to aircraft maintenance, repair and overhaul: A review. *In 2018 21st International Conference on Intelligent Transportation Systems (ITSC)* (pp. 150-156). IEEE.
- Saaty, T. L. (2004). Decision making—the analytic hierarchy and network processes (AHP/ANP). *Journal of systems science and systems engineering*, 13(1), 1-35.
- Saaty, T. L. (1980). *The Analytic Hierarchy Process*. New York: McGraw-Hill.
- Shukla, B., Fan, I. S., & Jennions, I. (2020, July). Opportunities for Explainable Artificial Intelligence in Aerospace Predictive Maintenance. *In PHM Society European Conference* (Vol. 5, No. 1, pp. 11-11).
- Singh, A., & Malik, S.K. (2014). Major MCDM Techniques and their application-A Review. *IOSR Journal of Engineering*, 4, 15-25.
- Vargas, R. V., & IPMA-B, P. M. P. (2010, October). Using the analytic hierarchy process (AHP) to select and prioritize projects in a portfolio. *In PMI global congress* (Vol. 32, No. 3, pp. 1-22).
- 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.
- Vincent, N. C., Bhakar, R. R., Nadarajan, S. R., Syamala, A., & Varghese, J. (2021). Impact of Artificial Intelligence in the Aviation and Space Sector. *In Artificial Intelligence* (pp. 209-229). CRC Press.

Wang, S., Zargar, S. A., & Yuan, F. G. (2021). Augmented reality for enhanced visual inspection through knowledge-based deep learning. *Structural Health Monitoring*, 20(1), 426-442.

Zeldam, S. G. (2018). *Automated failure diagnosis in aviation maintenance using explainable artificial intelligence (XAI)* (Master's thesis, University of Twente).



BIOGRAPHICAL SKETCH

Metin Emin Aslan completed his high school education at Ankara Atatürk Anatolian High School in Turkey. Then, he started his license education at the Department of Industrial Engineering in Middle East Technical University in 2012 and completed in 2017. Metin Emin Aslan, who started his Master of Science education in the field of Industrial Engineering at the Graduate School of Science and Engineering in Galatasaray University in 2019, performs his profession as a business analyst at Information Technology Department of an airline company.