

Article

Comparative Analysis of the Aviation Maintenance, Repair, and Overhaul (MRO) Industry in Northeast Asian Countries: A Suggestion for the Development of Korea's MRO Industry

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Abstract: Aviation maintenance, repair, and overhaul (MRO) has become more important to the air transport industry during the pandemic since it plays a crucial role in improving safety, ensuring profitability, and achieving sustainability in the industry. The growth of the Northeast Asian MRO market is forecasted to be remarkable, making the region the next MRO powerhouse. This study investigates the MRO industry in Northeast Asian countries (China, Japan, and Korea) to gain insights for strategical development of the industry. SWOT analysis was used to understand external macro-environment and internal conditions comprehensively, with comparative analysis then performed to find each country's competitiveness. SWOT analysis of the external environment of the aviation MRO industry in Northeast Asia finds opportunities from increased competition in the air transport industry and technological development and threats caused by aircraft advancements (less scheduled maintenance checks) and a limited workforce. Internal conditions are analyzed using six factors: cost, workforce, geographic presence, quality with shorter turnaround time, technological advancement, and certification. The results indicate that Korea's MRO industry has strong human resources but weak technological capabilities. The competitive advantage of the Chinese MRO industry stems from both a large number of aircraft and lower costs. While Japan possesses superior MRO technology, high labor costs reduce their industrial competitiveness. Based on a comparative analysis, this study provides strategic insights into the improvements that can be made in the Korean MRO industry. Since composite MRO of newer aircraft presents a small technological gap which can be overcome with high-quality human resources, Korea should focus its resources and policies on promoting the composite MRO industry due to its high growth potential.

Keywords: maintenance, repair, and overhaul; aviation; composite repair; industry forecasting; SWOT analysis; sustainability



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1. Introduction

Air transport has become the primary mode of long-distance travel for many customers, and the industry enjoys continuously rising demand [1,2]. This underscores the public interest in safety and a growing desire for improvements in the aviation sector. Comprehensive and efficient aircraft maintenance is necessary to ensure high safety levels [3]. Aviation maintenance, repair, and overhaul (MRO) refers to all activities related to managing and supervising aircrafts to function as required [4] and involves managing functionality while maintaining the aircraft's design, safety, and reliability [5]. A well-developed maintenance strategy is often applied to extend the expected aircraft lifespan [6]. The aviation MRO industry also supports continuous flights with minimum ground time [7]. This provides financial and nonfinancial advantages to the air transport industry, which became

more important in an adverse COVID-19 environment. MRO is also beneficial to important environmental, social, and governance (ESG) sustainability aspects. Effective MRO can reduce unnecessary production by recycling and minimizing the use of secondary parts, thus adding cost benefits. Environmental and economically positive impacts of the MRO industry can directly contribute to the sustainability of the air transport industry [8,9]; therefore, a strategic approach is required to support the industry at a national level. As such, the MRO industry plays an important role in improving the airline industry's safety, ensuring its profitability [10], and helping to achieve sustainability.

Individual countries are responsible for safety management in the aviation industry [11]. Therefore, accurate and sophisticated market analysis is essential in order for the aviation industry to be able to adapt appropriately to a rapidly changing external environment [12]. As of 2019, the total value of the Northeast Asian MRO market was estimated at approximately USD 14 billion, and the industry continued to show remarkable growth [13,14] before COVID-19. These figures indicate that Northeast Asia is geographically positioned to drive future changes in the aviation MRO industry. South Korea (hereinafter 'Korea'), Japan, and China are not only the key players in the MRO industry in Northeast Asia but are also representative of the industry in this region [15]. Therefore, this study analyzes trends in the region's MRO industry by focusing on these three countries and suggests future development directions for Korea.

The study considers each country's current resources and future trends to derive national insights for strategically promoting the aviation MRO industry. In this regard, a SWOT analysis has been performed to understand the region's external macro-environment and each country's internal conditions comprehensively. A SWOT analysis is a representative technique that considers a specific target's internal and external conditions to draw strategic implications [16,17]. In particular, this study uses a SWOT analysis to provide insights to improve the competitiveness of the MRO industry in the three countries. The external environment of the Northeast Asian MRO industry presented opportunities and threats [13], serving as a basis to establish a strategic stance to develop the industry's potential. We analyzed and compared three Asian countries' capability (i.e., strengths and weaknesses) to leverage forecast conditions and subsequently suggested developmental directions. Based on the comparative analysis results, we have attempted to propose strategies to promote the Korean aviation MRO industry and make it more competitive.

This study contributes two aspects to the literature: First, it serves as a reference for a logical research methodology using both quantitative and qualitative primary data collected from industry experts. Second, it analyzes the aviation MRO industry in three representative countries in Northeast Asia and suggests strategies that could be used to develop the aviation maintenance industry.

2. Literature Review

2.1. Understanding the External Environment of the Aviation MRO Industry

The aviation MRO industry has substantial entry barriers, including economies of scale, capital requirements, and related laws and regulations, including certification [18]. Even though manufacturers possess the required technology, significant entry barriers still exist at the business level. The MRO industry is a crucial part of the circular economy in the aviation industry due to its involvement in recycling or upcycling used parts to achieve sustainability. The aviation industry can achieve ESG targets through MRO, even when the industry has been under scrutiny over CO₂ emissions [9].

As such, governments must take the initiative to promote the MRO industry based on strategic blueprints. A strategic approach requires identifying future market fluctuations, including mid- to long-term industry trends. Since the aviation industry's response to the external macro-environment is very flexible [19], numerous studies have explored future uncertainty using various measures and methods.

To identify future conditions in the aviation industry, international organizations (e.g., the International Civil Aviation Organization (ICAO), Airports Council International

(ACI)) suggest guidelines and methods for effectively evaluating the market [18,20]. In academia, studies using autoregressive integrated moving average models and a methodology to reflect seasonality in forecasting have predicted future changes [21–24]. Understanding future trends is crucial, as this can serve as the primary data for devising strategies and making decisions [25]. Additionally, studies analyzing future conditions in practical or realistic terms have been actively conducted [13,14].

This study identifies future trends in the MRO industry based on aircraft volume, demonstrating a high correlation with industry characteristics. Choi [26] analyzed changes in the number of operating aircraft and the size of the MRO industry by region from 2015 to 2025. According to the correlation analysis, the two ratios—the number of aircraft operated by region and the size of the MRO industry—are predicted to change nearly identically, with the correlation coefficient of the two ratios being significantly positive at 0.99. That is, the more the aircraft are used, the higher the level of maintenance required, thereby increasing demand for MRO. Thus, the MRO industry’s demand is influenced by the volume of aircraft. Moreover, since different aircraft models require different MRO, demand varies according to aircraft models.

2.2. Competitiveness of the National Aviation MRO Industry

To survive by adapting to industry changes, a comprehensive understanding of the industry is essential [27,28]. Accordingly, this study uses six factors (defined in Table 1) to analyze current MRO industry conditions at a national level [13].

Table 1. Factors influencing the MRO industry.

Factor	Definition
Cost	The amount that must be spent to obtain an item or service. The cost of maintenance, repair, and overhaul services is paid by the airline to the service provider and includes labor and materials.
Workforce	The number of people working or available to work.
Geographic Presence	Existing or occurring in a specific geographical area/region.
Quality with Shorter Turnaround Time	Reduced time required to fulfil a process request without sacrificing service quality.
Technological Advancement	MRO-related prowess, maturity of related industries.
Certification	An official document attesting to a status or achievement level.

The factors summarized in Table 1 can be classified into three aspects. First, MRO demand is generated by various airlines, who spend 12–15% of their operating expenses on maintenance [29]. Cost is a key factor for securing the demand created by airlines and a source of competitive advantage. The cost of MRO services primarily comprises material and labor expenses [13]. Since aircraft MRO requires certified components and materials, material costs remain relatively constant across different countries. As a result, controlling labor expenditure is vital to keeping maintenance costs low in the aviation MRO industry. In addition to labor costs, the quality of human resources itself is a crucial factor. Shanmugam and Robert [30] suggested that factors related to human resources in the MRO industry influence maintenance quality. Yilmaz [31] analyzed potential risks in the MRO industry and human resource allocation. Samad, Haider, and Hairudin [32] administered structured and unstructured questionnaires to 30 practitioners to confirm how these factors related to human resources (e.g., personnel qualifications and technical guidance materials) and their influence on aviation safety.

Second, since aircraft do not generate revenue when undergoing maintenance, airlines try to minimize operational maintenance time. Thus, countries that enjoy geographical proximity can attract airlines that are planning their maintenance schedule. As the quality of MRO services affects aviation safety, shorter turnaround time, though critical, is not

sufficient. Therefore, the quality of maintenance provided is also a source of competitiveness in the MRO industry. To develop supplier process management in the Asian MRO industry, Ho et al. [33] identified the factors (including incentives, investments, business strategies) that affect process improvement and provided implications for effective and high-quality processes. Dhanisetty et al. [34] attempted to optimize the operational maintenance process using multiple decision-making criteria and presented techniques for minimizing maintenance costs and their respective time requirements with specific aircraft models. Through surveys, Machado et al. [35] analyzed the quality of outsourcing to enhance maintenance efficiency.

Third, technological factors are closely related to the scope of MRO demand. The latest advanced methods and materials are constantly applied to aircraft to ensure capability and reliability, thus enhancing air transport efficiency [36]. As such, diverse technological achievements related to aircraft maintenance are important factors in understanding the technological readiness of the domestic aviation MRO industry. For example, there are fundamental differences between the maintenance of composite (new materials) and conventional metals (metal, aluminum, and alloys). Unlike traditional materials, composites require non-destructive inspection techniques to identify defect type and condition, the performance of defect analysis, and the subsequent determination and confirmation of the repair method based on defect analysis. Studies on composite MRO have attempted to identify effective repair methods specific to composites rather than methods based on existing techniques [37,38]. The Federal Aviation Administration (FAA) prescribes specific requirements, regulations, and advisories for composite MRO [39]. Furthermore, certification is required to conduct such repairs; aviation authorities must ensure compliance with maintenance-related laws and regulations, and certifications are issued to maintenance companies to ensure a standard technological level and quality. Thus, certifications are essential when attempting to diversify maintenance demand; the more certifications a company obtains, the more potential maintenance demand it can secure.

2.3. SWOT Analysis

In a representative study, Flouris and Oswald [40] stated that a SWOT analysis is useful for aviation industry participants (typically airlines) and identifies their internal capabilities and external conditions while also helping in the strategy making process. Muhmmet et al. [41] presented the characteristics of Istanbul Airport and Turkish Airlines' new destination candidates using a SWOT analysis. Parton and Ryley [42] also conducted a SWOT analysis of charter airlines, seeking to compare and analyze factors for a specific airline. While the analytical results confirmed the importance of a negative external environment, they also demonstrated internal influences such as inadequate goal setting and organizational inefficiencies. Researchers have also used SWOT analysis in the aviation MRO industry. Vieira and Loures [29] assessed the internal and external capabilities of MRO industry-related stakeholders (original equipment manufacturers, repair shops, suppliers, and airlines). They found that stakeholders tend to adopt business strategies that expand partnerships despite the fierce competition for survival. Al-kaabi et al. [43] categorized the MRO activities of four airlines from a fully integrated MRO model to a completely outsourced model. Identifying the strengths and weaknesses of each MRO activity model, they provided insights to help airlines operate efficiently. The researchers also considered external conditions and proposed a strategic framework airlines could use to select an appropriate MRO configuration. Al-kaabi et al. [43] considered how to effectively select strategies for maintenance-related businesses at the individual airline level. This study extends their work to derive strategic measures to enable the growth of the maintenance sector at a national level.

3. Analytical Framework

The competitiveness of a country's MRO industry is affected by certain external and internal conditions. This study comprehensively analyzes the macro-environment using

the three research flows shown in Figure 1 to compare helpful development strategies in the MRO industry.

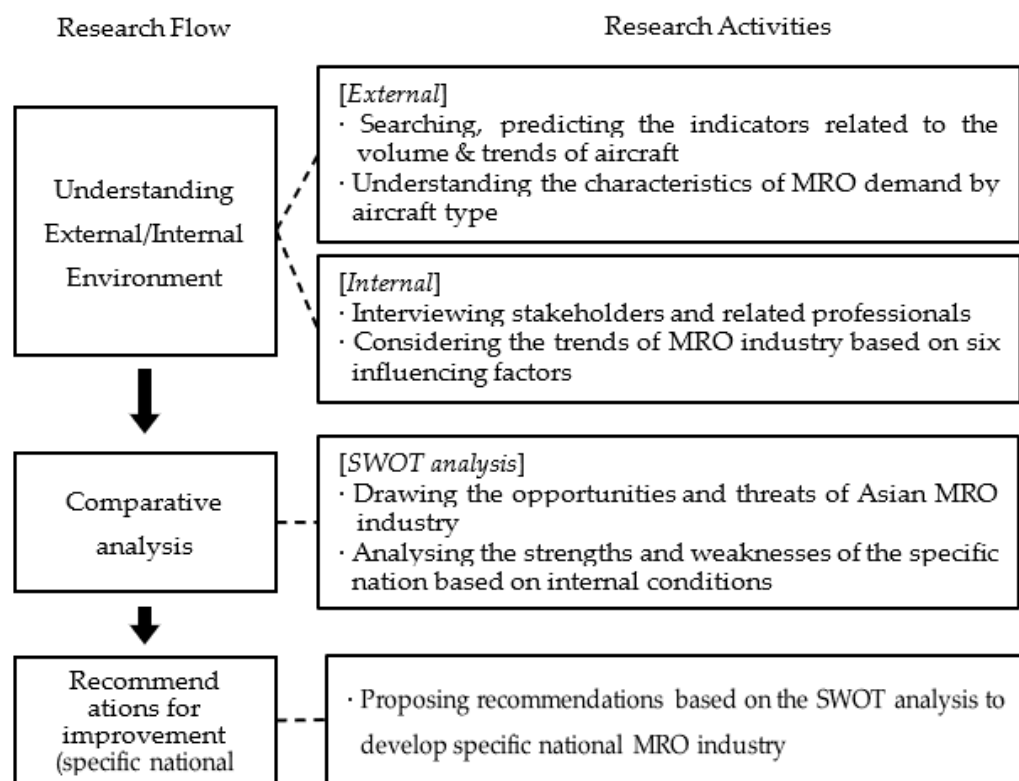


Figure 1. Analytical framework.

The first research flow of this study examines the external and internal environment of the Asian MRO industry. The MRO industry is not independent of the air transport industry but is closely related to the number of aircraft required. To draw implications for promoting the MRO industry, the first research flow starts by analyzing current and future aircraft trends in Northeast Asia based on Frost and Sullivan's [13] data. To identify mid- to long-term trends, this study analyzes the detailed characteristics of each aircraft model in the aircraft fleet. An aircraft model's characteristics vary by materials, applied technology, or maintenance cycle, and the demand in the MRO industry is determined by those characteristics.

The second research flow compares MRO industry competence among three countries. A SWOT analysis is performed by comprehensively considering the resources and limitations of each nation. The opportunities and threats are drawn from the external environment analysis conducted in the first flow. The external environment surrounding the Northeast Asian MRO industry can be categorized into opportunities that positively influence the industry and threats that have the opposite effect. Strengths and weaknesses are analyzed based on the six influencing factors outlined in Table 1. This study was conducted using primary and secondary data, including interviews with MRO practitioners and government organizations related to airworthiness across the Asia-Pacific region. The final research flow makes recommendations to develop Korea a major player in the MRO industry according to the strategy derived from the SWOT analysis. It derives implications for the industry's future, provides in-depth insights on the current state of affairs, and presents an outlook on the future of the regional aviation MRO industry.

4. Results of SWOT Analysis

The MRO industry complies with international standards (such as those prescribed by the ICAO) and an array of safety and quality standards and environmental regula-

tions (e.g., from the FAA and the European Union Aviation Safety Agency (EASA)) from countries with advanced aviation industries. This requires advanced technologies and facilities, various equipment, colossal investment costs, and a global sales network. As such, the MRO industry is a representative industry that requires government-led strategic promotion measures. It is essential to adopt a strategic approach considering both the present and the future. This section discusses the external factors impacting MRO industry demand and positive and negative country conditions that influence the effective use of the external environment.

4.1. External Conditions: Opportunities and Threats

In order to examine current conditions and the future size of the industry, Table 2 summarizes the number of aircraft expected to be in service over a five-year period, between 2020 and 2024, based on analysis by Frost and Sullivan [44]. Air transport demand surged in Northeast Asia between 2000 and 2010; however, political issues have directly and indirectly affected these countries since the late 2010s [45,46]. Moreover, the recent COVID-19 pandemic has negatively impacted the macro-environment, thereby causing a decrease in the scale of planned fleet expansion.

Table 2. Expected volume of in-service fleets in Northeast Asia [44].

Country	2020	2021	2022	2023	2024
Korea	242	303	377	429	504
China	2348	2964	3579	3921	4412
Japan	422	537	636	703	806
Total	3012	3804	4592	5053	5722

Figure 2 shows the predicted MRO demand in the three countries over the five-year period, as projected from this trend. Despite COVID-19, the demand for MRO generated in the three Northeast Asian countries is predicted to grow steadily at an annual average rate of 16–17% until 2024. This progress is likely because MRO industry demand is independent of the number of aircraft purchased in the future; rather, it depends on operational aircraft.

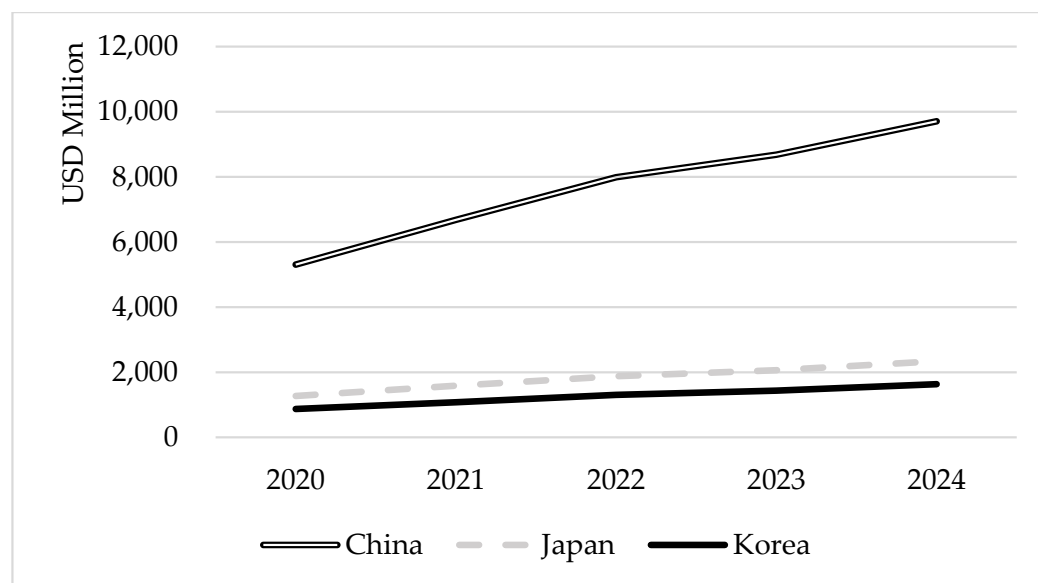


Figure 2. Total MRO spending forecast of three Northeast Asian countries [44].

The external environment of the aviation MRO industry in Northeast Asia presents five opportunities and seven threats, as summarized in Table 3. According to the analysis,

notable factors that positively impact MRO demand relate to intensifying competition in the air transport industry and the development of related technologies. As new airlines enter the market in Northeast Asia, competition intensifies, thereby signifying the importance of improving profitability to an airline's survival. With efforts devoted to operating medium- and long-haul routes, air transport industry participants must expand and modify their fleets to adapt to such routes. Quantitative and qualitative changes in fleets influence the volume and characteristics of MRO demand.

Table 3. External conditions of the MRO industry in Northeast Asia.

Influencing Factors	
Opportunities	Automation and robotics in maintenance, repair, and overhaul (MRO) operations.
	Predictive maintenance leading to better visibility from scheduled checks.
	New airlines entering the industry imply new business for independent MRO companies.
	Growing middle class leading to increased orders for aircraft.
	Sale and leaseback leading to an increased number of fleet orders.
Threats	Increased competition causing airlines to postpone non-essential MRO work.
	Consolidation in the market resulting in less opportunity for independent MRO companies, as more operations are handled in-house.
	Highly sophisticated MRO processes are returning to Original Equipment Manufacturers (OEMs).
	Cybersecurity is an important consideration for MRO companies.
	Limited workforce restricts MRO operations.
	Aircraft advancements lengthen the interval between scheduled maintenance checks.
Flight time reduction caused by COVID-19 affects MRO spending, accelerates restructuring and retirement of traditional aircraft, and places an emphasis on newer aircraft.	

Technological development is another primary driver of change in demand. Predictive maintenance is one factor with notable effects on the current industry. Advancements in big data and Internet of Things (IoT) technologies—such as smart sensors and aircraft condition monitoring systems—have enabled the real-time collection and analysis of aircraft operating data, thereby changing the maintenance environment and enabling predictive maintenance. One Korean national airline introduced predictive maintenance in 2014 and expanded its scope of application [47]. Based on a wide range of repair data collected from aircraft, the airline can establish systematic maintenance plans, thus maximizing fleet operation efficiency [47]. Technological advancements are also expected to impact industry participants. Automation and robotization can positively influence maintenance quality and enhance maintenance result reliability. In other words, applying advanced technology in the aviation industry improves the reliability of scheduled maintenance and enables the MRO industry to operate more effectively.

By contrast, negative forecasts for the MRO market stem from two key causes. First, aircraft advancements extend the interval between scheduled maintenance checks. This aspect is a major cause of declining demand and arises from the introduction of new aircraft models with longer maintenance cycles. Aircraft models possess different intrinsic characteristics (such as components, introduction time, and applied technology) that influence the MRO industry differently. Newer aircraft models (e.g., B787 and A350) possess characteristics different from existing traditional aircraft models (e.g., B767, B747, and B737). Unlike past models, the MRO demand for new models is reduced because newer models typically eliminate or extend heavy maintenance cycles, such as the C or D check [48,49]. Moreover, the retirement of traditional aircraft and the introduction of newer aircraft to replace them are expected to exacerbate the MRO market's decline. Particularly, the B787 and A350 models most commonly used by airlines are expected to show significant growth

over the next five years; they are predicted to comprise nearly 7% of Korea, China, and Japan's fleets in 2023.

Second, a limited workforce, which restrains MRO operations, is another factor that will substantially influence the industry over at least the next five years. Since the MRO industry requires advanced technology and is based on a licensing system, it is systematically managed through type rating, requirements, and the necessary workforce. Therefore, human resources must be effectively and efficiently managed for the MRO industry to operate optimally. Boeing predicts demand for 260,000 new workers in the Asia-Pacific region by 2037, reflecting the emerging need for a skilled workforce [50]. However, the next-generation maintenance workforce cannot serve as an adequate replacement for the current ageing workforce; while the labor demand in the MRO industry is rapidly growing, the labor supply currently being trained is insufficient. Additionally, the current MRO workforce must receive adequate training and keep manuals and techniques up to date. The imbalance between the supply and demand for labor negatively influences employers to use a workforce with unsuitable MRO field experience and qualifications.

Moreover, the recent introduction of newer aircraft exacerbates the shortage of human resources equipped to handle new technologies. For example, labor cost for B747s accounted for 51% of the total MRO cost, whereas for the latest model, the A350, labor cost accounts for 65% of the total MRO cost [12]. This signifies that the newer the model, the higher the demand for human resources trained to maintain the model, leading to an imbalance between supply and demand. Managing human resources as the share of newer aircraft grows over the next five years is critical.

4.2. Internal Conditions: Strengths and Weaknesses

According to the external environment analysis, the most noteworthy change in the MRO industry is the increased use of newer aircraft and a corresponding demand for human resources to maintain those aircraft. By performing a comparative analysis for Northeast Asian countries, the strengths and weaknesses that form their source of competitiveness can be analyzed based on six factors.

4.2.1. Workforce and Cost

Human resources with suitable capabilities and qualifications are vital in the aviation industry, particularly in the MRO industry. The human resources required for the aviation MRO industry can be analyzed with respect to quality and cost. This section analyzes the quality and cost of human resources in each country while considering the potential supply and demand that is required in the future. To secure a high-quality human resources pool for the aviation MRO industry, workers must prepare themselves to use new technologies and the latest professional materials from advanced countries. The overall state of human resources can be analyzed using two indicators: English proficiency and average education level.

First, aircraft maintenance is carried out based on certain standards, such as manufacturers' manuals. These standards are determined by international organizations (e.g., the ICAO) or related institutions in advanced aviation countries (e.g., the FAA and EASA) and are typically prescribed in English. Indeed, the FAA requires maintenance personnel to be proficient in English comprehension, reading, and writing [39]. Moreover, the disciplines that require a fundamental understanding of aviation MRO (e.g., aerodynamics, material engineering, and aviation-related laws, among others) cannot be covered in primary and secondary schools but must be taught at higher levels. Korea's population has a moderate level of English proficiency compared to other Northeast Asian countries [51]. If countries that use English as an official language are excluded (e.g., Singapore, the Philippines, Malaysia, and India), Korea has the highest English proficiency level in Asia. Korea has one of the largest proportions of highly educated human resources among member countries of the Organization for Economic Co-operation and Development (OECD) [52]. As such, the education level indicator reflects the excellent potential of Korea's human resources.

Figure 3 shows the wages of aviation MRO industry workers in Asian countries with representative MRO industries (Korea, China, Japan, Australia, and Singapore). Since airlines prefer shorter turnaround time for MRO service, these five Asian countries compete geographically in the Asia-Pacific region. As shown in the graph, China has a lower wage rate than the other countries. This factor can reduce the cost of MRO. As maintaining newer aircraft requires a larger share of labor costs than in the past, this reduced labor cost can be advantageous over competing countries.

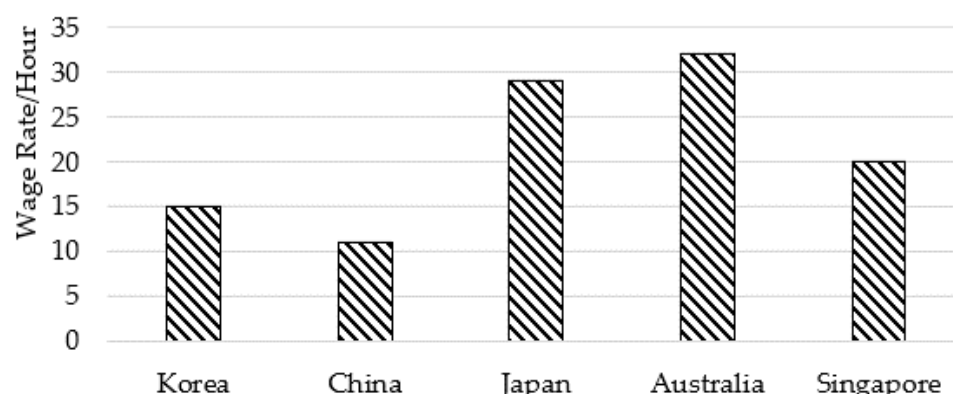


Figure 3. Average MRO technician wage rate/hour (USD), 2020.

4.2.2. Geographic Presence and Quality with Shorter Turnaround Time

The geographically closer the aircraft is maintained, the lesser the turnaround time and the lower the corresponding cost. Korea is located between China and Japan, and Incheon International Airport, its representative airport, serves as a hub for Pacific routes. Thus, Korea, considering the Incheon International Airport (a hub airport with geographical advantages and easy accessibility), is even more competitive. Furthermore, the construction of MRO-related industrial complexes at a national level, such as the Incheon and Sacheon complexes currently under development, can lead to economies of scale via integration.

MRO operators ultimately seek to provide maintenance services with fast and high-quality results. Thus, competitiveness depends on a high on-schedule rate and a high level of maintenance quality, represented by the mean cycles between failures and reliability after maintenance service [53]. In Korea, performing maintenance on a national aircraft comprises approximately 62–78% of the work occupancy of non-Korean approved maintenance organizations [54]. Additionally, issues with offshore maintenance quality continue to arise [55]. Hence, Korea can expect advantages in its maintenance quality and turnaround time competitiveness compared to competitor countries.

4.2.3. Technological Advancement and Certification

Based on an analysis of mid- to long-term trends in fleet volume, this study found that the composition of fleets in Northeast Asia gradually shifted to newer aircraft. Due to the inherent risks in aircraft operation, players in the air transport industry have traditionally faced strict regulations [56], among which environmental regulations on carbon dioxide emissions and fuel cost pressures have catalyzed the introduction of new technologies. The major new technologies are closely related to the high use of composites. Composites can serve as a solution that allows for the production of lightweight aircraft and can help enhance engine efficiency (e.g., by increasing the bypass ratio or reducing weight as opposed to increasing the size of engine fan blades). The newer the aircraft model, the more this technology is being used. Therefore, composite parts (e.g., fuselage, wings, doors, stabilizers, control surfaces, radomes, and tail cones) account for more than 50% of the materials in newer aircraft, such as the B787 and the A350. Table 4 provides more details [44].

Table 4. Share of composites in airframe MRO spending [44].

Aircraft Model	% of Composites	Proportion of Airframe Spending Attributed to Composites
B767, B747, B777, A330	5%	10%
B737, A319, A320, A321, A321neo	15%	30%
A220, A380	20%	40%
B787	50%	100%
A350	53%	100%

Sales of traditional aircraft that use composite materials show a 6% compound annual growth rate, whereas newer aircraft show approximately twice the growth rate. Since the volume of newer aircraft is forecasted to grow to around 440 aircraft by 2023, a focus on and selection of newer aircraft is essential. Carbon fiber-related technologies are primarily used with aircraft using composite parts. Carbon fiber-related products in Korea, China, and Japan showed a comparative advantage of 0.94, 0.07, and 3.41, respectively [57]. Japan enjoys technological strengths based on national-level efforts regarding R&D projects and the strategic cultivation of composite technologies.

Therefore, obtaining technological advantages could positively impact Japan's competitiveness in terms of diversifying certifications. Since MRO companies can only repair components or parts for which they are certified, certification is another necessary consideration for securing demand. However, the composite MRO industry requires maintenance processes, certification systems, and infrastructure, among other elements that differ from traditional MRO and technological factors distinct from composite production. Therefore, compared to the traditional MRO industry, technological issues, including certification, are more likely to be overcome through strategic policies.

5. Comparative Analysis of the MRO Industry: China, Japan, and Korea

This study's findings have the goal of leveraging strengths and opportunities, transforming weaknesses, and neutralizing threats according to the internal and external conditions of the MRO industry. Specifically, with regard to external conditions, the key is to prepare for the technologies required to maintain the next generation of aircraft. Future maintenance demand is projected to decline as technological advances lengthen the maintenance schedule cycle. Furthermore, this trend is expected to drive major changes in the MRO industry in the future (e.g., the need for a large and high-quality workforce to maintain newer aircraft). Specifically, as the use of the B787 and A350 by Northeast Asian airlines is projected to increase, the MRO demand for these models is expected to change proportionally [12]. Consequently, while the demand for traditional MRO services is expected to decline, it should positively influence the demand for composite MRO services, considering the high proportion of composite parts in these models.

The findings on each country's internal conditions are summarized in Figure 4. The status of each country with respect to the six identified factors is evaluated at three levels: high, middle, and low. The level of these countries is assessed by 10 experts who have been in the MRO industry for more than 15 years. Korea is considered to be somewhat less competitive than the other two countries. Japan is dominant in terms of technological prowess but suffers disadvantages in terms of cost and geographical location. Based on internal and external environment analysis results, we suggest implications for Korea to offset its disadvantages and reinforce its competitive advantages. The aviation MRO industry is a major part of the aviation industry at the national level owing to both labor-intensive requirements and high value-added high technology and contributes to the creation of a lot of jobs. These comprehensive implications can provide insights that can direct the strategic development of the aviation MRO industry at the national level.

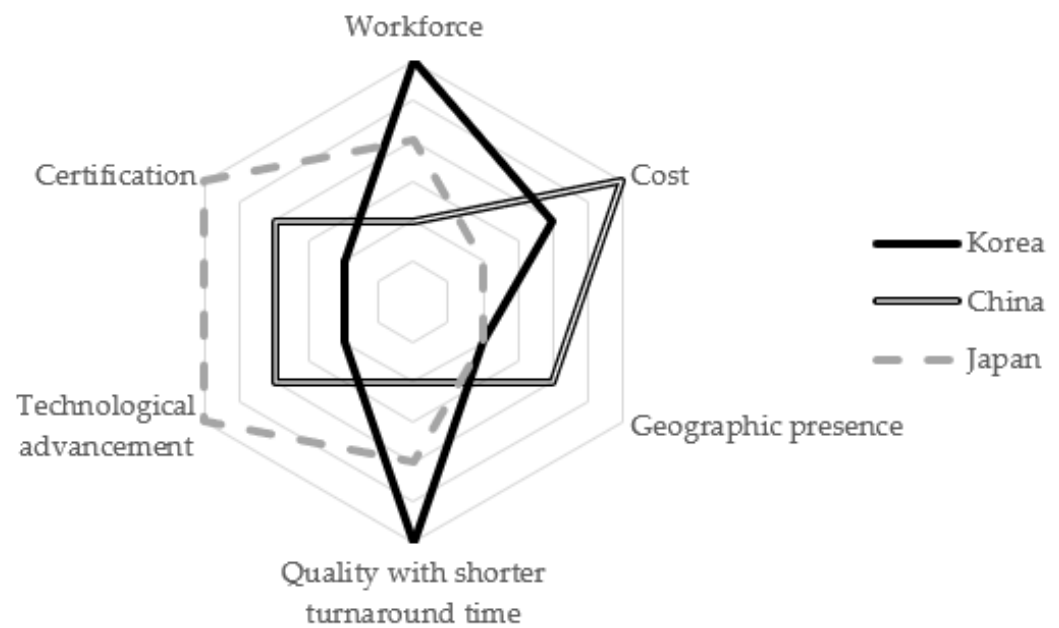


Figure 4. Comparative analysis of three Northeast Asian countries.

Implications for A Specific Country's MRO Industry: A Case Study of Korea

According to the SWOT analysis (Table 5), Korea possesses high-quality human resources, medium wages, and a high technological level compared to China. Compared to Japan, it possesses high-quality human resources, low wages, and a low technological level. Therefore, although Korea has high-quality human resources overall, it is positioned between China and Japan. On this basis, this study provides strategic directions in two aspects for the future development of Korea's MRO industry.

Table 5. Internal conditions for Korea's maintenance, repair, and overhaul industry.

Influencing Factors		Intensity
Strength	Supply of high-quality human resources (high education level and English proficiency)	Medium
	Price competitiveness owing to relatively low labor costs	Medium
	Korea's geographically advantageous location between China and Japan	Low
	Quality with shorter turnaround time	Medium
Weakness	Low technological advancement related to composites	Medium
	Relatively low number of MRO providers with certifications	Medium

First, the composite MRO industry should serve as the solution to the challenge of developing the Korean MRO industry. In traditional MRO industries, such as aviation maintenance or heavy maintenance industries dominated by other Northeast Asian competitors, it is difficult for Korea to secure competitive advantages in terms of its current technological level and recognition. In the field of composite MRO, the relevant methods and certifications are currently being established. Moreover, given that the relevant technologies are comparatively new, the gap between Korea and its competitors is believed to be smaller compared to the traditional MRO industry. With high-quality human resources who can quickly adopt the next-generation technologies required in the composite MRO industry, Korea can take advantage of the market's abundant growth potential and overcome the disadvantages of being a latecomer to the MRO industry.

Second, operators should apply innovative technologies across manufacturing and related facilities in the MRO industry to enhance operational efficiency and safety [12].

These technological improvements have previously reduced MRO companies' reliance on labor, particularly simple and labor-intensive work; however, input that requires creative and critical thinking has increased due to the characteristics of newer aircraft [12]. Korea's strengths stem from its high-quality human resources. However, education is needed to help this workforce adapt to and fully understand the industry's characteristics. Augmented reality (AR) and virtual reality (VR) technologies are suitable for reducing the time needed for training and improving skill retention levels [12] and have recently found use in industrial fields that require a variety of specialized skills. Given the lack of time available to train skilled technicians, compared to the expected rise in demand for workers, it is essential to use these new technologies. Considering high costs in the early development stages, these technologies must be systematically introduced at a national level. MRO industry participants must develop human resources that best meet their needs. Applying AR/VR technologies is an alternative method for increasing the proficiency of employees and improving the quality of human resources. Therefore, both industry and government need to pay attention to these technologies from a strategic perspective.

6. Conclusions

In the aviation industry, safety is closely related to product quality. An understanding of the MRO industry is essential when managing quality in the sector. This study identified potential changes in the MRO market (including composite MRO) over the next five years in three Northeast Asian countries. The region's market volume is projected to increase based on China's growth trend. This aspect is attributed to the accelerating trend of replacing traditional aircraft, which might lead to the quantitative growth of the aviation industry over the next five years thanks to the latest aircraft models having longer maintenance cycles. There are also negative factors that exert a complex influence on the MRO market, consequently slowing down the growth trend. This study also analyzed the capability and potential of each country according to six factors (cost, workforce, geographic presence, quality with shorter turnaround time, technological advancement, and certification) that influence the MRO industry, thus comparing the current and future prospects of each country in this regard. The internal conditions indicate that Japan has technological advantages, while China has cost advantages. Korea has advantages in terms of human resources and quality over shorter turnaround time but is placed in a comparatively unfavorable position in regard to technological advancements and labor costs.

A strategic approach to developing a country's MRO industry can strongly support the environmental initiatives of the ICAO (CORSIA) [58] and help accomplish an airline's ESG targets, thus positively impacting its performance [59,60]. This also positively impacts sustainable aviation industry growth, which is critical to the world economy.

Furthermore, this study suggests a strategic direction for the Korean aviation MRO industry. In this regard, the MRO industry for newer aircraft is closely related to the composite MRO industry, and Korea should secure high-quality human resources, which is an essential factor in the composite MRO industry. Moreover, to foster the composite MRO industry, Korea should establish a system for development based on basic aviation policy, research suggestions, and the convergence of various industries to become a new player in this field. Korean government plans to promote the aviation MRO industry should include human resources development and job creation, which would thus make Korea more attractive to employers requiring highly skilled employees.

Nevertheless, this study has the following limitations, which must be addressed in follow-up studies to derive more refined findings. The SWOT analysis results could not be compared to those of other researchers due to a lack of similar studies in the field. Since the data used offer long-term forecasts, they are not sensitive to short-term fluctuations. However, the overall impact of the recent pandemic on the aviation industry is significant, and the negative repercussions can persist in the long term. Thus, future studies need to consider the long-term effects of COVID-19.

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