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Determinants Affecting Air Cargo Operational Performance in Thailand: A Strategic and Mixed-Methods Approach

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Abstract

Background and Aims: The operational effectiveness of air cargo is a critical factor in global supply chains, as it impacts both economic growth and commerce efficiency. This study aims 1. To evaluate the impact of human, technological, cargo handling, and environmental factors on the operational efficiency of air cargo in Thailand, 2. To explore the practical insights associated with air cargo performance efficiency, and 3. To propose strategies for enhancing air cargo operational performance.

Methodology: The authors employed a sequential explanatory mixed methods approach to investigate the determinants affecting air cargo operational performance. We investigated the impact of human, technological, cargo handling, and environmental factors on the operational performance of air cargo. Quantitative data were initially gathered via a survey of 431 participants, comprising cargo operation agents, customs officers, airport managers, and cargo handling and airline personnel in Thailand. Thirteen key informants were purposefully chosen to ensure their roles and experiences were highly relevant to the air cargo industry. Criteria included five years of professional experience, and involvement in critical areas such as cargo handling, capacity management, storage, operational coordination, or regulatory compliance.

Results: It revealed significant relationships across all variables, with technological advancements exhibiting the strongest influence, followed by human factors, cargo handling processes, and environmental factors. In the subsequent qualitative phase, thematic analysis highlighted the critical role of technology including sorting technologies for loading/unloading, real-time tracking, predictive analytics such as demand forecasting, route optimization, and dynamic pricing integrating with human factors such as training, motivation, and teamwork to improve operational performance.

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Conclusion: The operational efficiency of air cargo is greatly affected by the adoption of advanced technologies, the improvement of human resource management, and the optimization of cargo handling processes, while considering environmental and external factors.

Keywords: Air cargo operations; Operational performance; Technological advancements; Cargo handling efficiency; Human factors; Environmental factor; Mixed methods research

Introduction

Air cargo transport plays an important role in the global supply chain as it has facilitated the economic development of nations. Air freight enables the swift and reliable connection of customers to distant markets through geographic locations. The business substantially impacts worldwide GDP, facilitating millions of employment opportunities in the logistics, warehousing, and aviation sectors. Air cargo offers a secure and efficient way of transporting high-value shipments such as electronics, luxury items, and jewelry. Live animals require a controlled environment and prompt transport. Pharmaceuticals like vaccines, biologic, and temperature-sensitive drugs require cold chain logistics. Fresh produce, seafood, and flowers must be delivered quickly to maintain quality and safety. Air cargo supports global supply chains by ensuring timely and safe delivery. (Sales, 2013; Tzimourtos,2015, Carman et al., 2019). Global air cargo demand has risen notably, with a 10.3% year-on-year increase in 2024 (IATA, 2024). This growth is accompanied by challenges, including capacity constraints during peak seasons, necessitating investments in infrastructure and fleet modernization to enhance efficiency. Additionally, the industry is undergoing a digital transformation, leveraging technologies like blockchain and artificial intelligence to streamline operations and improve customer experiences (Ali et al., 2022). As the use of artificial intelligence (AI) in cargo operations grows, increase the risks and challenges that come with it. Cybersecurity threats, such as data breaches and system hacking, are a significant source of concern because they can disrupt operations and jeopardize customers' sensitive information. This results in data breaches that may harm an organization's reputation and finances. Rapid technological advancements, environmental concerns, and changing consumer demands are putting pressure on the air cargo industry. Consumer demands for faster, more reliable, and transparent services complicate matters. To stay competitive in a

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changing global market, strategic innovation, operational efficiency, and adaptability are needed.

Objectives

1. To evaluate the impact of human, technological, cargo handling, and environmental factors on the operational efficiency of air cargo in Thailand
2. To explore the practical insights associated with air cargo performance efficiency
3. To propose strategies for enhancing air cargo operational performance.

Review Literature

1. Performance metrics for air cargo services

Air cargo operations involve shipping goods. This includes packaging, processing, transporting, and delivering goods (Tzimourtos, 2015). The success of operations depends on stakeholders' efficiency and cooperation. Following ICAO standards for legislation, operations, airworthiness, personnel licensing, and organizational structure is mandated. Passengers view airline on-time performance as the most tangible indicator of service excellence (Prince &Simon, 2015). Many travel websites track this for customers. The percentage of shipments delivered on time is crucial because it makes customers happy and trust operations (O'Connell, 2020). On-time delivery is calculated by dividing on-time shipments by total shipments. Predicting air freight capacity for capacity utilization is difficult. How to evaluate cargo space utilization, including weight and volume load factors. The optimal use of potential loading weight, loading area, or both is often achieved by chance. High utilization rates indicate excellent resource and financial efficiency (IATA, 2024). These KPIs help airlines identify bottlenecks, improve operations, and meet customer expectations. Accurate demand forecasting in the air cargo industry improves capacity utilization and load factor, boosting efficiency (Lee et al., 2021; Garg et al, 2024; Liu et al., 2020). Cargo Damage Rate (CDR) is another key measurement of cargo handling quality and efficiency. It shows the percentage of cargo shipments damaged during transportation, loading, unloading, or storage. High damage rates can cost money, damage customer trust, and lead to legal issues. Customer satisfaction is a common air operation efficiency measure. Safe practices reduce accidents, injuries, and cargo damage. To handle and transport goods safely, firms must follow regulatory standards and implement strong safety protocols. It reduces cargo handling

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risks (Merkert & Alexander, 2018). Effective cargo risk management involves analyzing and improving packing and stowage processes. High cargo space utilization improves operational efficiency, while robust tracking systems improve risk management and safety compliance.

According to the review, Key performance indicators, including on-time performance, capacity utilization, cargo damage rate, financial performance, and customer satisfaction are essential for enhancing operational quality. Timely performance improves customer satisfaction and trust, whereas effective capacity utilization and accurate demand forecasting enhance financial efficiency and resource optimization. Robust safety and compliance protocols are essential for risk mitigation, damage reduction, and the preservation of the aviation safety record. These metrics assess air cargo operations to improve efficiency, fulfill customer expectations, and sustain competitive advantage.

2. Human Factors in Air Cargo Operations

Human factors are integral to operational performance, acting as both enablers and potential barriers. Critical human factors influencing air cargo operational efficacy. Effective communication, fatigue management, and a safety-centric culture are essential for improving safety, minimizing human error, and enhancing overall operational performance in air cargo. (Merkert & Alexander, 2018). Competency-oriented errors arise from insufficient training or experience, resulting in mistakes during crucial processes. Insufficient supervision may lead to operational errors, increasing the probability of accidents (Kilic & Gundogdu, 2020). In the loading and unloading truck bay, essential equipment includes a security system and additional productive personnel (Nath & Upadhyay, 2024). The effects of employee communication, coordination, and morale on the effectiveness of cargo operations. Clear communication and teamwork facilitate better coordination, quicker problem-solving, and smoother operations, especially in high-stakes environments. Insights into challenges such as staff retention, workload management, and skill shortages are also relevant to their performance. Human performance is adversely affected by stress and fatigue, leading to errors and reduced efficiency. Optimizing these factors leads to better safety, efficiency, and productivity. Thus, the following hypothesis has been proposed.

H1: There is a significant relationship between the Human factors and Operational performance.

3. Technological Advancements and Their Impact on Air Cargo Efficiency

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Technological advancements have significantly enhanced the efficiency and reliability of air cargo operations. Digitalization and automation are transforming cargo handling, tracking, and documentation processes. For instance, advanced cargo management systems enable real-time tracking and monitoring, improving transparency and customer satisfaction (Kumar & Altalbe, 2024). Additionally, the adoption of Internet of Things (IoT) devices facilitates seamless monitoring of cargo conditions, such as temperature and humidity, ensuring the safe transportation of sensitive goods (Liu et al., 2020). The integration of blockchain technology has also enhanced data security and transparency in supply chain operations, fostering trust among stakeholders (Merkert & Alexander, 2018). The freight management system's overall performance, dependability, and visibility are improved by the simplification of cargo handling made possible by AI-facilitated technological advancements and driverless cars (Tzimourtos, 2015). These technologies have provided quicker and more reliable/accurate solutions. By leveraging these advancements, air cargo operators can achieve improved operational quality, cost efficiency, and customer satisfaction. The integration of technology in air cargo operations, including automation in cargo handling, digitalization of the supply chain's procedures, and improvements in real-time cargo tracking systems, impacts cargo operations. Therefore, the following hypothesis has been suggested.

H2: There is a significant relationship between Technological Advancements and Operational performance.

4. Cargo Handling Factors and Operational Efficiency

Cargo handling processes, including loading, and unloading efficiency, equipment functionality, and infrastructure adequacy are very important for efficient operation. An organized logistics process, including the integration of material and information flows, is essential for optimizing efficiency. The efficiency of the handling process improved through the optimization of various factors, including bottlenecks, resources, and warehouses.

(María et al., 2012) Insufficient ground equipment and poorly managed turnaround times would lead to have impact on the operational bottlenecks, in air cargo performance. Intelligent logistics algorithms for path optimization, intelligent scheduling, and data mining optimize the cargo process. Artificial intelligence (AI), blockchain, and autonomous vehicles help streamline cargo handling, which enhances performance, reliability, and visibility throughout the freight management system (Li et al., 2024). Hence, the following hypothesis has been suggested.

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H3: There is a significant relationship between Cargo Handling Processes and Operational Efficiency

5. Environmental and External Factors Influencing Air Cargo Operations

Air cargo operations are significantly influenced by various environmental and external factors, including weather conditions, regulatory requirements, and market dynamics. The air cargo market is sensitive to global economic changes, impacting demand and operational costs (Reinhold et al., 2013). Increasing environmental regulations require air cargo operators to adopt greener practices. Air cargo contributes to greenhouse gas emissions, primarily from fuel combustion, which poses a challenge to sustainability efforts (Wang et al., 2023). Aircraft noise and emissions are important environmental factors. Mitigation strategies involve technological innovation, operational strategies, fleet management, and policy development. Stakeholders must work together to effectively address these environmental issues in air cargo operations. (Lay et al., 2016). Hence, the previous has been suggested the following hypothesis.

H4: There is a significant relationship between Environmental & External Factors and Operational Efficiency

Conceptual Framework

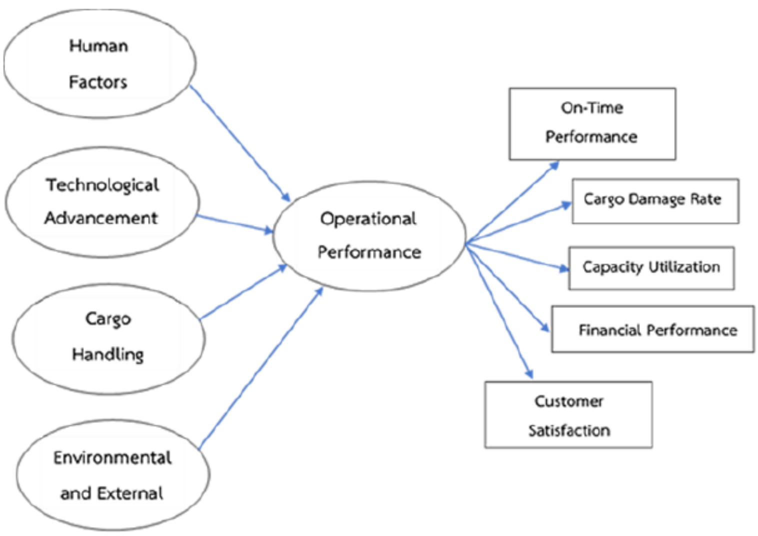

Figure 1 Conceptual framework model on the air cargo operational efficiency

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Figure 1 illustrates those human factors such as skills, training, communication, and motivation directly influence operational performance. Technology acts as an enabler by automating processes, improving accuracy, and reducing delays that influence operations. While cargo handling practices ensure operational integrity. And external factors require adaptability to maintain consistent outcomes. Consequently, these variables interact to influence operational performance.

Methodology

1. Study design

To fully address Thailand's complex air cargo operational performance determinants, the authors employed the explanatory sequential mixed-method design as illustrated in Figure 2. This approach uses quantitative data collection and analysis to determine how human, technological, cargo handling and environmental factors affect operational efficiency. The qualitative phase provides context and explains the quantitative findings. Integrate both data types for a comprehensive analysis that quantifies relationships and provides actionable strategies to enhance air cargo performance. We designed 2 phases for collecting and organizing data. The quantitative study was conducted first to obtain the result of the objective which is to analyze the influence of those determinants on the performance of air cargo operations. Then followed by a qualitative study to support the quantitative results. The quantitative data indicated the direction of the qualitative study, and the qualitative data provided context to the quantitative results (Creswell & Plano Clark, 2011).

Integration, the core element of mixed-methods research is their integration. A conscious attempt to integrate qualitative and quantitative research methodologies to achieve a harmonious connection that leads to a greater understanding of an issue. Explicitly defining a mixed methods design can assist researchers in the planning of a study and in orienting readers to the methods used in the study (Creswell et al., 2003; Creswell & Plano Clark, 2011; Fetters et al., 2013; Creamer, 2018). Therefore, the authors employed an explanatory sequential design to integrate the system at the design level. The objective of implementing this methodology was to determine the factors that influence the operational performance of air cargo and to discover how to optimize the operations. The initial phase of this two-phase design (see Figure 2) entailed the collection and analysis of surveys in which participants rated their agreement on the determinants affecting air cargo operations

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using a five-point scale as quantitative data, followed by the collection and analysis of interviews. The cargo operation efficiency was evaluated by participants based on four categories: the human factor, advanced technologies, the cargo handling process, and the environment and external factors. We first analyze the quantitative data and subsequently employ the quantitative findings to establish sampling criteria for the subsequent qualitative phase.

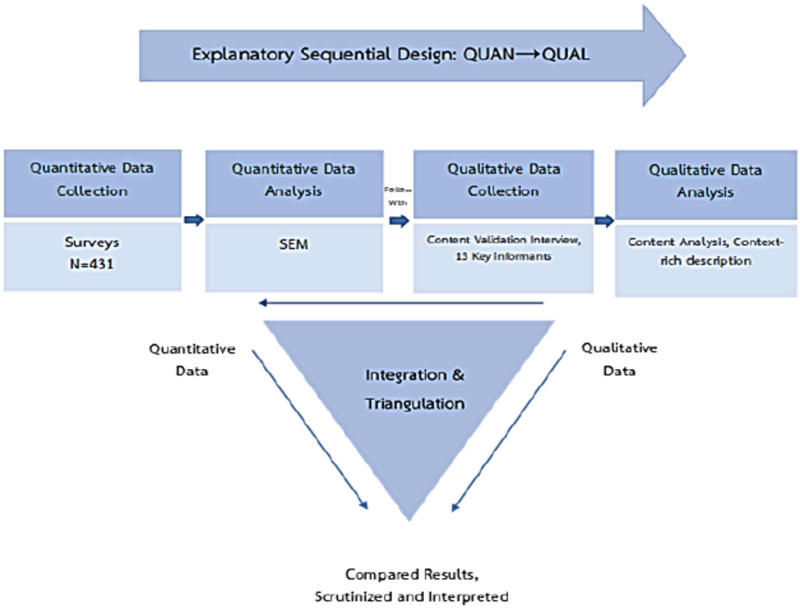

Figure 2 Explanatory sequential study design procedures

2. Sampling and methods

For the Quantitative Phase, participants were recruited from three major cargo, airport workers, customs officers, and personnel handling agents in Thailand. Additionally, the researcher employed a Google form within open groups for air transport personnel that featured a filter question: "Are you working related to air cargo, cargo acceptance, or cargo handling?" If affirmative, they are eligible for answers to the details of the question as in Table 1.

Table 1: Details of respondents

Respondents	Questionnaire returned	% of Respondents
Cargo Operation Agents	251	58.24
Customs Officers	18	4.18
Airport Managers	24	5.57
Airline Staff	85	19.72

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Respondents	Questionnaire returned	% of Respondents
Handling Company	53	12.29
Total	431	100

For the Qualitative Phase, the researchers employed a purposive sampling technique to select 13 participants for the study. The participants are in the air cargo business and met the following criteria: a) a minimum of five years of experience in air cargo-related roles; b) have contributed to resolving operational bottlenecks, enhancing cargo efficiency, or role in regulatory compliance, inspections, and customs; and c) Involved in air cargo handling, storage, capacity management, and operational coordination. The research participants are highly experienced in cargo handling procedures, air cargo operations, customer service, air freight regulations, and safety standards. To ensure that they are aware of the advantageous outcomes of operational efficiency strategies

3. Data collection

For quantitative data collection, we distributed questionnaires to respondents at the companies. The survey consisted of a cover letter and emphasizing that participation was voluntary and the guarantee of response confidentiality. Additionally, an online survey was conducted. This paper's primary objective is to concentrate on personnel of air cargo companies in Thailand which comprise cargo operation agents, customs officers, airport managers, airline staff, and personnel from the handling company.

Qualitative data collection, A semi-structured interview was conducted with participants. The concept aimed at exploring the practical insights associated with air cargo performance. Face-to-face, semi-structured interviews using an interview guide were performed to explore the depth of cargo operational efficiency and the influencing factors. Additionally, the interview questions were altered during the meetings. The interview questions were guided by the survey results and operational efficiency theory. Continuous data collection was implemented until saturation was achieved. All interviews were audio recorded with the participant's consent and transcribed verbatim at the earliest possible opportunity. Participants provided both numerical answers and qualitative descriptions.

4. Analysis

In quantitative analysis, four factors are regarded as independent variables: human factors, technological advancements, cargo handling factors, and environmental and external

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factors. While operational performance is examined as a dependent variable. Data analysis using the LISREL Software. Analyzed separately and then triangulated to establish the strategies. Data analysis using the LISREL Software 8.72. Analyzed separately and then triangulated to establish the strategies.

In qualitative analysis, two researchers studied the interviews through thematic analysis. We follow the s six-step guide includes familiarizing with data, creating initial codes, creating themes, revising potential themes, defining themes, and drafting the final report (Braun & Clarke, 2006).

Results

1. Respondents' socio-demography

After randomly distributing the online survey questionnaires and distributing them to companies, there were 431 valid outcomes in return, where 58% of the active respondents are males, 40% are females, and the remaining 2% identify as other. As in the case of their age-based demographics, 42 participants are less than 25 years old, 141 are 25 to 35 years old, 156 are 35 to 45 years old, 64 are 45 to 55 years old and 28 of them are more than 55 years old. Well, as far as their experience in the related field is concerned, it becomes concluded that 13.33% of them have less than two years of experience, 42% have 2 to 5 years of experience, 21.18% have 5 to 8 years of experience, and 23.49% of them having more than 8 years experience of working related air cargo and logistics. Participants for the in-depth interview (n =13; Table 1), with air cargo employees and authority officer informants, were selected from the survey sample. The participants represented 5 executives of 3 air freight companies, 6 highly experienced workers from airlines, airports, and handling agents, and 2 from authorities. The demographic statistics show that most of the participants are highly experienced and educated persons who know all the pros and cons of air cargo operational efficiency.

2. Quantitative results

This research model consists of 5 latent variables, including Operational Performance (OPP), Cargo Handling Processes (CHP), Technologies Advancements (TNA), Human factors (HMF), and Environmental & External Factors (EEF). Determining the relationships between each latent variable and the others to measure the model is one of the most important processes in assessing a latent variable's reliability and consistency. Determining the validity

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of the indicator variables used to measure latent variables is the goal of latent validity testing. The loading factor value, represented by standardized regression weights, serves as a metric for evaluating the validity of each indicator in the measurement of latent variables. The loading factor value is > 0.5, convergent validity properties will be achieved based on a good loading factor size. Validity testing results are illustrated in Figure 2 and Table 2. The data in Table 3 indicate that the loading factor values for the OPP, CHP, TNA, HMF, and EEF variables exceed 0.5. The values indicate that these indicators are valid for assessing latent variables.

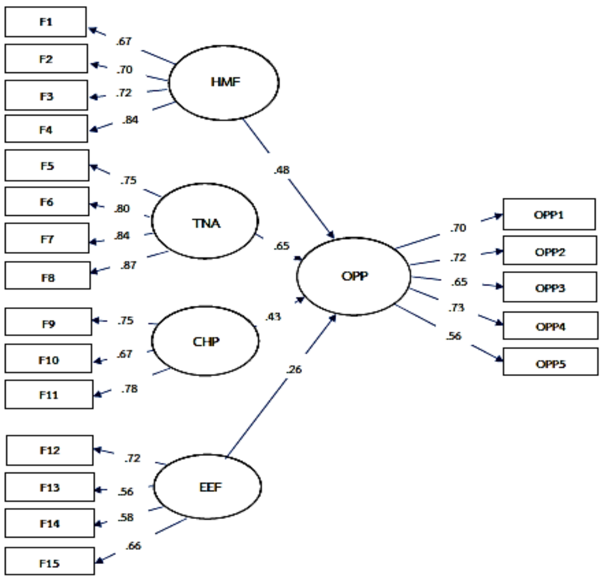

Figure 3 Structural Equation Model. Note: OPP=Operational Performance; HMF=Human Factors; TNA= Technologies Advancements; CHP=Cargo Handling Processes; EEF=Environmental & External Factors. For the normalized fit index (NFI) values greater than .90 are required. The incremental fit index (IFI) is acceptable when above .90, and excellent if it surpasses .95. When the RMSEA is less than 05, it is deemed excellent; when it is below.08, it is considered acceptable.

The proposed structural equation model exhibits a robust fit across all evaluation metrics based on the participant number in the study. Goodness-of-fit indices: Normed Chi-square (CMIN/DF) = 1.301, p- value 0.104; GFI= 0.973; AGFI= 0.944; CFI= 0.953. The RMSEA yielded an excellent value of .046. The proposed SEM aligns well with the data, as evidenced by the consistently strong fit indices. The robustness of these results shows that the model

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accurately represents the relationships between the key constructs (OPP, HMF, TNA, CHP, EEF)

Table 2 Construct validity test

Latent Variables	Indicators	Loading Factors	Criteria	Descriptions
Operational Performance (OPP)	OPP1	0.704	0.5	Valid
	OPP2	0.722	0.5	Valid
	OPP3	0.648	0.5	Valid
	OPP4	0.732	0.5	Valid
	OPP5	0.561	0.5	Valid
Human Factors (HMF)	HMF1	0.669	0.5	Valid
	HMF2	0.703	0.5	Valid
	HMF3	0.721	0.5	Valid
	HMF4	8.837	0.5	Valid
Technologies Advancements (TNA)	TNA1	0.753	0.5	Valid
	TNA2	0.802	0.5	Valid
	TNA3	0.844	0.5	Valid
	TNA4	0.868	0.5	Valid
Cargo Handling Processes (CHP)	CHP1	0.749	0.5	Valid
	CHP2	0.667	0.5	Valid
	CHP3	0.781	0.5	Valid
Environmental & External Factors (EEF)	EEF1	0.720	0.5	Valid
	EEF2	0.563	0.5	Valid
	EEf3	0.584	0.5	Valid
	EEF4	0.656	0.5	Valid

Hypotheses Testing

The examination of the structure requires the testing of hypotheses that the model formulated. The relationships between the constructs indicate the hypotheses in the model, as presented in Table 2.

Table 3 The results of a hypothesis test

Hypothesis	Structural path	β	t value	p-value	Decision
H1	Human factors ⟶ Operational performance	0.481 sig	3.342	0.001**	Accept H1

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Hypothesis	Structural path	β	t value	p-value	Decision
H2	Technological Advancements ⟶ Operational performance	0.652 sig	4.115	0.001**	Accept H2
H3	Cargo Handling Processes ⟶ Operational performance	0.434 sig	3.265	0.01*	Accept H3
H4	Environmental & External Factors ⟶ Operational performance	0.256 sig	2.831	0.05	Accept H4

Note: * $p < 0.05$, ** $p < 0.01$, p*** < 0.001, Sig. = statistically significant relationship

Table 3 demonstrates the impact of factors on the cargo operational performance. Hypothesis H1 (Human factors ⟶ OPP) shows a β value of 0.481 ($p = 0.001$), indicating its critical role. Human factors encompass the skills, expertise, decision-making abilities, and overall well-being of personnel involved in air cargo operations. To confirm Hypothesis H2, Technological advancements, including automation, artificial intelligence (AI), Internet of Things (IoT), and data analytics, have revolutionized air cargo operations. Automation of processes such as cargo sorting, tracking, and documentation enhances efficiency and reduces human error. Hypothesis H2 (Technological Advancements ⟶ OPP) shows the strongest relationship with a significant β value of 0.652 ($p = 0.001$), highlighting its primary influence. In support of Hypothesis H3, it shows a moderate impact with $\beta = 0.434$ ($p = 0.01$). The cargo handling process involves the physical transfer, categorization, and storage of goods from their point of origin to their destination. Effective management processes are essential for preserving the integrity of the cargo, complying with timelines, and maximizing resource efficiency. Delays or mismanagement during loading or unloading may result in financial losses, customer dissatisfaction, and reputational harm. Finally, the Hypothesis H4 (Environmental and external factors ⟶ OPP) exhibits the lowest influence ($\beta = 0.256$, $p = 0.05$), although still significant. Environmental and external is include weather conditions, regulatory frameworks, and economic fluctuations. Fuel prices, labor strikes, and geopolitical conflicts.

3. Qualitative results

Utilizing the saturation principle, we performed depth interviews through semi-structured formats. Our analysis yielded three major themes explaining air cargo operational efficiency, which are human factors in cargo operations, operational processes and efficiency,

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and regulatory and policy environment. Table 4 shows the various themes, sub-themes, explanations, and quotations.

Table 4 Thematic analysis of semi-structured interviews.

Themes	Subthemes	Excerpts from interviews	
Human Factors	Training and Competency	-A skillful and well-trained cargo agent understands standardized cargo handling. They know the proper loading, unloading, and stacking techniques. This reduces errors such as cargo damage, incorrect placement, or safety violations. - Regular training and adherence to SOPs (standard operating procedures) increase smooth flow of cargo operation	“We have been trained regularly to be able to safely and efficiently handle different types of cargo.” [P02]
	Motivation and Satisfaction	Workforces feel valued and supported can translate into faster turnaround times and fewer errors in the process.	“Motivation is important. When our efforts are recognized, it makes us handle cargo with extra care.” [P05]
	Team Collabora tion and Communi cation	Sharing real-time updates about flight schedules, cargo weight, and handling instructions reduces errors like missed flights or incorrect load distribution.	“In air cargo, teamwork is everything. It’s not just about doing our job but it’s about supporting each other.” [P07]
Operation al Processes and Efficiency	Technological Integration - Real-Time Tracking and Monitoring. - Automated sorting, loading, and unloading systems.	- Human expertise with technological advancements makes operations run smoothly. - Technology has significantly streamlined our operations and helped reduce turnaround times. - The combination of automation, real-time data, and predictive tools has been a game-changer for our operations - Smart contracts to streamline payment.	"Thanks to real-time updates for monitoring the cargo, we can easily allocate resources and prepare for incoming goods. It's good for everyone involved.” [P02] “I think using AI will make it easier for me to follow the rules.” [P01]

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Themes	Subthemes	Excerpts from interviews	
	Digitalization and Data Analytics - Implementation of electronic airway bills (e-AWB) and documentation systems.	-By using IoT devices, cargo conditions can be checked in real-time, which ensures quality of service. - E-freight solutions, such as electronic airway bills and customs pre-clearance systems, have reduced paperwork processing times.	“We've cut down on the time it takes to process shipments by switching to digital documentation.” [P04] “Advanced scheduling software, helps us to allocate resources better.”
	Process Optimization	- Use of robotic arms for cargo handling in warehouses helps streamline operations.	“Adding an inventory management system to our setup has made storing things easier." [P08]
	Time Management and Prioritization	A skilled cargo agent prioritizes tasks effectively, ensuring critical operations are handled first without compromising quality.	I always focus on the critical shipments first. It’s not about rushing. You must handle it with care.” [P01]
	Coordination between Stakeholders (e.g., airlines, ground handlers, freight forwarders).	Team collaboration and communication minimize errors. Investing in communication training, digital collaboration tools, and fostering a culture of teamwork are essential strategies.	“Good planning and coordination are essential for loading and unloading so I think experience is important” [P05]
Regulatory and Policy Environment	Compliance with Regulations	Agents with strong knowledge of customs regulations and documentation requirements can accurately prepare and verify documents (e.g., airway bills, and shipping manifests). This reduces errors that could lead to fines or shipment delays.	“When we follow safety protocols everything runs smoother.”[P10]
	Environmental & External factors	Environmental and external factors impact the management of air cargo such as weather conditions, can disrupt schedules, leading to delays and	“I think reducing waste not only helps the planet but also cuts operational

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Themes	Subthemes	Excerpts from interviews	
		increased operational costs. Fluctuations in economics and fuel prices impact cost structure.	costs and streamlines workflows.” {P11]

The thematic analysis highlights critical determinants influencing air cargo operational performance, as derived from semi-structured interviews. Key themes include Human Factors, emphasizing training, motivation, and collaboration, which enhance accuracy and teamwork. Operational Processes and Efficiency showcase technological integration, digitalization, and process optimization as pivotal in reducing errors and improving turnaround times. Additionally, the Regulatory and Policy Environment underscores the importance of compliance with regulations and environmental practices for operational smoothness and sustainability.

Discussion and conclusion

Our results show that the most influential factor affecting air cargo operational performance is technological advancement followed by human factors. The findings align with previous research those technological advancements demonstrated the strongest impact on operational performance, as evidenced by their ability to streamline operations through automation, digitalization, and real-time tracking systems. Technologies enhance organizational agility and increase airline performance by enabling faster decision-making (Jandaboue et al, 2024). The adoption of IoT and advanced cargo management systems has been shown to enhance transparency and reduce delays, as supported by Kumar & Altalbe (2024). RFID technology allows to reduce the risk of damage due to human errors (Giusti et al., 2019). Modern systems and technologies significantly enhance cargo operations by improving efficiency, reducing errors, and optimizing processes through automation and advanced analytics (Spandonidis et al (2022). By P06*, "Using an application for baggage sorting reduces errors because everything is automated and precise".* However, human factors, including training, motivation, and collaboration, are also important in improving performance Effective training programs enable agents to handle cargo with precision, reducing errors and maintaining high operational standards (Nath & Upadhyay, 2024). Cargo handling, though in third place, remains an essential factor of air cargo operations. Efficient

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loading, unloading, and storage processes are vital for maintaining the integrity of shipments and adhering to delivery timelines. Integrating technological advancements with efficient processes enhances operational excellence, driving continuous improvement performance (Vishnu, 2024). Nonetheless, certain studies reject these findings. Yadav & Goriet, (2022) argue that external and environmental factors, such as fuel price fluctuation, aircraft maintenance, and labor cost are primary factors that significantly impact the airline's operational performance. Human factors like teamwork, communication, and adherence to safety protocols can reduce errors and delays job satisfaction of employees boosts the accuracy and reliability of the operations. Ryczynski (2024) emphasizes that the overall reliability and efficiency of air cargo operations can be enhanced by the availability of company resources, such as experienced personnel and adequate training.

The findings reveal that technological advancements have the strongest influence on operational performance, significantly improving efficiency through automation, real-time tracking, and digitalized processes (β = 0.652, $p < 0.001$). Human factors, such as training, teamwork, and motivation, were also critical (β = 0.481, $p < 0.001$), underscoring the importance of skilled and collaborative personnel. Cargo handling processes (β = 0.434, $p < 0.01$) and environmental/external factors (β = 0.256, $p < 0.05$) play significant roles by ensuring operational integrity and resilience against external challenges. The study suggests investing in predictive analytics for demand forecasting and blockchain for supply chain transparency to improve air cargo operations. Continuous training and motivation in human resource management improve performance reliability. Robotic automation and intelligent scheduling optimize cargo handling, reducing delays and damage. Policymakers should promote sustainable practices like reducing emissions and waste to align the industry with global environmental standards.

Limitations and Future Research

This study primarily focused on air cargo operations in Thailand, which may limit the generalizability of the findings to other regions with different regulatory, operational, or environmental and market conditions. Although the sample size is sufficient for the context, It may not capture all perspectives in the complex air cargo industry. Additionally, the reliance on self-reported data from survey participants and interviews could introduce

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response biases. Further research could compare air cargo operations across countries or regions to better understand their global dynamics. To track the effects of changing regulations and technology, ongoing research is recommended. Air cargo performance may be better understood by considering environmental sustainability or geopolitical factors.

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