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LLMs-Based Weighting for MCDM: Case Study in Logistics Performance Index

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Abstract

Purpose: *The aim of this paper is to conduct an experimental study to determine whether large language models (LLMs)-based weighting is suitable for Multi-Criteria Decision Making (MCDM) or not. In addition, analyzing the prompt design effect is the other purpose of this study.*

Design/methodology/approach: *In this study, experiments were carried out based on prompts to determine the ranking and weights of six criteria (customs, infrastructure, international shipments, logistics competence and quality, timeliness, tracking and Tracing) in the Logistics Performance Index (LPI).*

Findings/results: *The findings revealed that prompt design is the most critical part to integrate LLMs in the MCDM context. Results show that there is not a single compatible LPI ranking, and the answers of ChatGPT differ with different prompt types (zero-shot, few-shot, and Chain of thought) and decision makers (supply chain director and academician).*

Practical implications: *The findings of this study are beneficial for researchers in the MCDM area who want to integrate LLMs in the field. The study will help not only the professionals in the logistics sector but also the beginners.*

Originality/value: *There are some recent studies using LLMs in the MCDM context. To the best of our knowledge, it is the first study used in logistics performance evaluation.*

Keywords: *LLMs, prompt; ChatGPT; LLMs-based weighting; MCDM; logistics; Logistics Performance Index; generative artificial intelligence*

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1. Introduction

Multi-Criteria Decision Making (MCDM) techniques are beneficial in the presence of conflicting criteria to rank the alternatives, to select the best alternative, and to classify the alternatives. There are numerous MCDM techniques. Some of them are used to determine the weights of each criterion, and some of them make it possible to rank the alternatives based on their own algorithms.

Developments in Artificial Intelligence (AI) have transformed research areas. MCDM research area was also influenced by the development in Generative Artificial Intelligence (GenAI). Literature shows the early attempts of pre-trained large language models (LLMs) usage in the MCDM area. It was reported that LLMs were used in domains such as question answering, professional consulting, and code generation in this context (Wang and Wu, 2024). Frederico (2023) also reported that Chat Generative Pre-Trained Transformer (ChatGPT) can help and support the supply chain's decision-makers. ChatGPT is an AI chatbot based on advanced LLMs, and it was developed by OpenAI (Park et al. 2025).

Some of the researchers (Wang and Wu, 2024; Dehghanimohammadabadi and Kabadayi, 2025; Lu et al., 2025; Park et al., 2025; Svoboda and Lande, 2025; Wang et al., 2025) tried to understand whether ChatGPT (as a virtual expert) can replace MCDM experts and compared the results of real and virtual experts.

There are mainly two kinds of weighing in MCDM: subjective and objective. There are some studies in the literature in which ChatGPT was used as a virtual expert in subjective MCDM techniques like Analytic Hierarchy Process (AHP) (Svoboda and Lande, 2025; Dehghanimohammadabadi and Kabadayi, 2025; Lu et al., 2025; Park et al., 2025; Wang et al., 2025). Domain expertise is crucial in AHP, not only in making pairwise comparisons but also in defining hierarchical structure and maintaining logical consistency (Park et al. 2025).

These studies were carried out in diverse areas such as supplier evaluations (Wang and Wu, 2024; Dehghanimohammadabadi and Kabadayi, 2025), supply chain evaluation (Wang et al., 2025), air quality evaluation (Wang et al., 2025), and customer satisfaction evaluation (Wang et al., 2025). Increase in speed, quality, accuracy, and objectivity, efficiency and reliability, decrease in time, cost, and bias (Wang and Wu, 2024; Svoboda and Lande, 2025) are the expected results of LLMs usage in MCDM techniques.

However, the LLMs-based MCDM research area is still immature. According to "diffusion of innovation theory," Rogers (1983) identified five adopter categories: Innovators (2.5% of adopters), early adopters (13.5%), the early majority (34%), the late majority (34%), and laggards (16%) (Wamba et al. 2024). It is highly important to carry out studies to make contributions to the literature.

These studies used LLMs as a way of implementing an MCDM technique instead of using software / MS Excel spreadsheets or replacing human experts with virtual experts to make pairwise comparisons. To the best of our knowledge, there is no study that uses LLMs as a new MCDM technique for weighting and ranking. In this study, there is an attempt to see the capabilities of ChatGPT as a virtual MCDM technique to see whether it can produce consistent weights or not. Three research questions (RQs) are listed below:

RQ1: Is LLM-based weighting suitable for MCDM?

RQ2: Which type of prompt (zero-shot, few-shot, Chain of Thought (CoT)) is better to get the result?

RQ3: Are the weights consistent?

Answering these research questions makes it possible to contribute to both the MCDM, performance management, and prompt engineering areas. First of all, this study will be one of the pioneer studies in the LLMs-based MCDM area, and the results of the study will contribute to the weighting techniques in the MCDM area. In addition, this study also contributes to the logistics performance management area in which MCDM techniques are frequently used, as explained in the literature review part in detail. Lastly, prompt design is a crucial part of communication with AI, and the results of this study will contribute to this area by proposing prompt templates. In a nutshell, the contributions of this research can be listed as follows:

- LLMs' usage in the field of weight determination in the MCDM context
- LLMs usage in the field of logistics performance management
- The effect of different prompt strategies

The paper is organised as follows. The following section provides a literature review about MCDM usage in performance measurement with LPI. The next section consists of methodology based on prompt design. The study continues with the results and the discussion. The conclusion part is the last section, which includes limitations and recommendations for future studies.

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2. Literature Review

LPI is the acronym of "Logistics Performance Index," which was presented by the World Bank biannually since 2007 to measure the performance of logistics activities based on a worldwide survey of logistics professionals. The seventh edition compares 139 countries based on defined criteria (The World Bank Report, 2023). To calculate overall performance scores, six criteria are used, and these criteria are equally weighted. These six criteria are listed as follows:

- Customs (C1)
- Infrastructure (C2)
- International shipments (C3)
- Logistics competence and quality (C4)
- Timeliness (C5)
- Tracking and tracing (C6)

It helps to gain a competitive advantage (Işık et al., 2020), and it is used to identify improvement areas and investment in logistics infrastructure by policymakers and practitioners (Çıray et al., 2024). It is also used for training logistics professionals (Çıray et al., 2024).

The main criticism of the LPI is the equal weight assumption (Gürler et al., 2024). There is considerable literature proposing some of the MCDM techniques to determine the weights of LPI criteria based on these comments. The results of the Chejarla et al. (2022) literature review study about performance evaluation of logistics based on 124 research articles (2010 to 2019) show that most of the papers (64%) used MCDM methods. Table 1 shows some of the studies that used MCDM techniques to determine the weights of LPI criteria in the literature based on countries and MCDM techniques.

Table 1: Literature Review about MCDM Studies based on LPI Scores

	Ulutaş and Karaköy, 2019	Yildirim and Adigu-zel Mercangoz, 2020	Işık et al., 2020	Mesic, 2022	Çalık et al., 2023	Hadzikadunic et al., 2023	Çıray et al. 2024	Gürler et al., 2024	Yılmaz, 2025	Özekenci, 2025
Countries										
European Union member states	√					√		√		
OECD countries		√			√					√
Top 23 countries									√	
11 Central and Eastern European Countries			√							
Western Balkans				√						
139 Countries							√			
MCDM Techniques (for weighting LPI criteria)										
Fuzzy AHP		√			√					
SWARA	√									
FUCOM						√				
Entropy							√	√		
SV			√							
CRITIC	√			√		√			√	√
MEREC										√
LOPCOW										√
SD										√
MCDM Techniques (for ranking countries)										
MARCOS				√		√		√		
WASPAS						√		√		
EDAS						√		√		

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	Ulutaş and Karaköy, 2019	Yildirim and Adiguzel Mercangoz, 2020	Işik et al., 2020	Mesic, 2022	Çalık et al., 2023	Hadzikadunic et al., 2023	Çiray et al. 2024	Gürler et al., 2024	Yılmaz, 2025	Özekenci, 2025
TOPSIS					√				√	
CRADIS										√
CoCoSo								√		
CODAS					√			√		
COPRAS								√		
GRA								√		
MABAC			√					√		
MOORA								√		
OCRA								√		
VIKOR					√					
ORESTE							√			
ARAS-G		√								
ARAS						√		√		
Integration Techniques (to integrate the results of MCDM techniques)										
AWM										√
Copeland								√		
Borda count					√					
Bonferroni						√				

Table 2 presents some of the LPI criteria weights in the literature. To make it easy to determine and compare the ranking of criteria for readers, Table 3 was derived from Table 2 to show the rankings. Although the weights differ according to year, country, and MCDM technique, results show that mostly C3 is the criterion placed in the first rank with the highest weight. On the other hand, mostly C4 is the criterion placed in the last rank with the lowest weight.

Table 2: LPI Criteria weights in the literature

Criterion*	Ulutaş and Karaköy, 2019 CRITIC (EU Countries)	Mesic, 2022 CRITIC (Western Balkan)	Çalık et al., 2023 AHP(OECD countries)	Hadzikadunic et al., 2023 CRITIC (EU countries)	Hadzikadunic et al., 2023 FUCOM (EU Countries)	Hadzikadunic et al., 2023 Bonferroni (EU Countries)	Özekenci, 2025 CRITIC (OECD countries)	Özekenci, 2025 AWM(OECD countries)
C1	0.183**	0.119	0.182	0.153	0.132	0.142	0.169	0.170
C2	0.180	0.166	0.213	0.154	0.121	0.137	0.141	0.155
C3	0.225	0.185	0.134	0.219	0.224	0.221	0.218	0.175
C4	0.119	0.156	0.203	0.127	0.149	0.138	0.116	0.153
C5	0.157	0.207	0.164	0.192	0.179	0.185	0.165	0.165
C6	0.135	0.168	0.078	0.155	0.195	0.174	0.192	0.182

**The ranking of criteria based on the World Bank Report. The readers need to be careful that in each article, the number of criteria is different.*

***Some of the values were 0.xxxx, and some of them were 0.xxx. To make a consistency. 0.xxx was adopted.*

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Table 3: LPI Index Criteria Rankings from highest to lowest

Ulutaş and Karaköy, 2019 CRITIC (EU Countries)	Mesic, 2022 CRITIC (Western Balkan)	Çalık et al., 2023 AHP(OECD countries)	Hadzikadunic et al., 2023 CRITIC (EU countries)	Hadzikadunic et al., 2023 FUCOM (EU Countries)	Hadzikadunic et al., 2023 Bonferroni (EU Countries)	Özekenci, 2025 CRITIC (OECD countries)	Özekenci, 2025 AWM(OECD countries)
C3	C5	C2	C3	C3	C3	C3	C6
C1	C3	C4	C5	C6	C5	C6	C3
C2	C6	C1	C6	C5	C6	C1	C1
C5	C2	C5	C2	C4	C1	C5	C5
C6	C4	C3	C1	C1	C4	C2	C2
C4	C1	C6	C4	C2	C2	C4	C4

3. Methods

In this study, the aim is to carry out experiments based on prompts. Firstly, theoretical information about prompt design is provided in this section. Secondly, the designed prompts are explained in detail. Figure 1 shows the workflow diagram of this study.

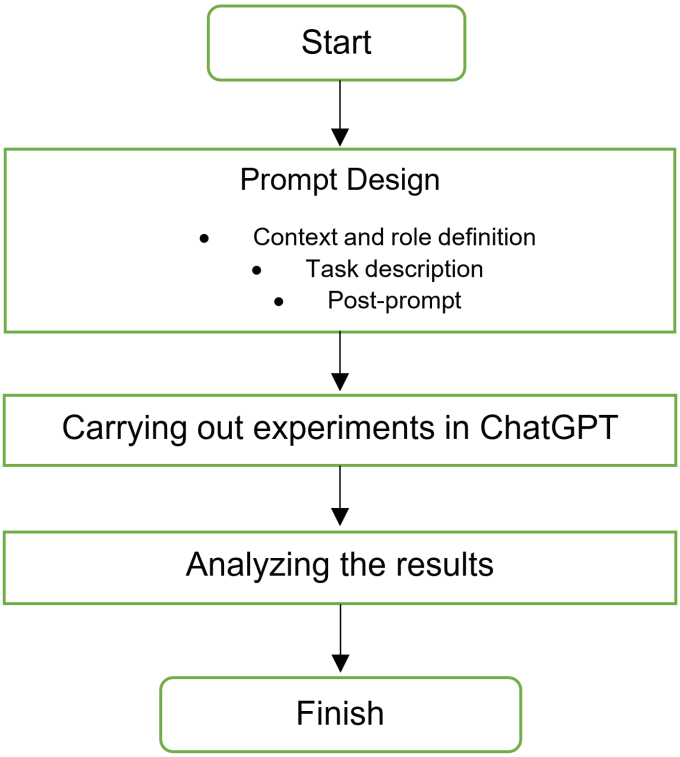

Figure 1. Workflow of the study

Prompt Design

Bozkurt (2024) defines prompt engineering as "*the art of communicating and interacting with generative AI*" and introduces some useful principles and strategies. To avoid queries that are too complex or specialized, to break down complex tasks into a series of simpler questions, and to employ a strategy of sequential questioning are some of the principles (Bozkurt, 2024). In addition to assigning a role or persona, providing contextual background, identifying the scope, specifying the format, and identifying the target group or audience are some of the strategies proposed in this paper (Bozkurt, 2024). Due to the hallucination risk, Bozkurt (2024) also advises a strategy to ask for proof.

To obtain optimal results, applying pre-trained models to specific domains directly is not suitable (Wang et al., 2025). Frederico (2023) also highlights that it is highly important to ask plausible questions to provide accurate answers from ChatGPT. Ray (2023) also attracts attention; it is possible to improve the relevance and quality of the AI-generated responses with such prompt engineering techniques. The prompt method is crucial for relatively difficult tasks (Lu et al., 2025).

The study of Wang et al. (2025) shows three prompt approaches. The task description is provided directly without any examples in the first approach, called "zero-shot". The second approach, called "few-shot", aims to help the model with a small number of task-specific examples. "Chain of Thought (CoT)" is the third approach in which a step procedure is followed to get the final answer. The accuracy rate increase was reported by Wang et al. (2025) via CoT or few-shot prompting. The LoRA-based fine-tuning technique was also reported for further performance improvement (Wang et al., 2025).

Ray (2023) gathers up the advice overlapping with Bozkurt (2025) for prompts in five steps:

- Start with clear and specific prompts
- Provide context and background information
- Specify desired format and structure
- Apply constraints and limitations
- Iterative prompting

In the study of Wang and Wu (2024), the prompt has three main parts: the prefix prompt, main content, and post prompt. On the other hand, Dehghanimohammadabadi and Kabadayi (2025) followed a three-step approach in prompt development: context specification, persona crafting, and instruction configuration. They also added a refinement process to enhance the AI's performance

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through iterative development with testing and iterative feedback.

Svoboda and Lande (2025) created "AHP Guide" as a special custom ChatGPT. Park et al. (2025) provided that the AHP model hierarchies consist of criteria, sub-criteria, and their weights in the Appendices. These model hierarchies start with the reference model as a ground truth and continue with AHP models created by LLM without and with presenting criteria, AHP models created by LLM without and with presenting criteria and sub-criteria, fine-tuning LLM AHP without and with presenting criteria, fine-tuning LLM AHP without and with presenting criteria and sub-criteria.

In this study, the prompt design contains three main parts: Context and role definition, task description, and post-prompt.

The roles were defined based on the information of real experts in Çalık et al. (2023)'s article and role definition examples in Wang et al. (2025). There are two main roles in this study. The first decision maker (DM1) is a supply chain director, and the second decision maker (DM2) is an academician.

The task described takes into account examples in Wang et al. (2025), Dehghanimohammadabadi and Kabadayi (2025), Svoboda and Lande (2025), and Park et al. (2025). There are three prompt types Wang et al. (2025) used in this study: Zero-shot, few-shot, and CoT. The weights determined by Hadzikadunic et al. (2023) and Özekenci (2025) were used as Example 1 (E1) and Example 2 (E2) in few-shot prompts. The reason for the selection of these examples is that they used more than one MCDM technique and combined them.

Park et al. (2025) pointed out that LLMs can uncover novel evaluation criteria that human experts might overlook. In the post-prompt part, PP1 tries to learn new criteria in light of this information. In addition, to check consistency, a post-prompt (PP2) was added to compare two random criteria. It is advised to apply a refinement process if the results are not satisfactory in the study of Dehghanimohammadabadi and Kabadayi (2025). In this study, there is no need to make a refinement process because the results are satisfactory.

Zero-shot and few-shot prompts contain only one prompt. Each CoT type prompt consists of 7 prompts. There are a total of 18 prompts generated with the prompts parts below. ChatGPT is used as an LLM in this study.

Context and Role definition part:

DM1: "*You are a supply chain director, and you have ten years of expertise in the logistics sector, possessing the ability to evaluate logistics sector performance*."

DM2: "*You are an academician, and you have ten years of expertise in the logistics sector, possessing the ability to evaluate logistics sector performance*."

Task description part:

Zero-shot

"*There are six criteria: Customs, infrastructure, international shipments, logistics competence and quality, timeliness, tracking, and Tracing. You are required to assess the weights of each criterion. The results of each criterion should be between 0 and 1. In addition, the sum of all weights should be 1."*

Few-shot

"*There are six criteria: Customs, infrastructure, international shipments, logistics competence and quality, timeliness, tracking, and Tracing. You are required to assess the weights of each criterion. The results of each criterion should be between 0 and 1. In addition, the sum of all weights should be 1.*

Example 1 (E1): Here is an example from the study of Hadzikadunic et al. (2023): weight of customs: 0.142, weight of infrastructure: 0.137, weight of international shipments: 0.221, weight of logistics competence and quality: 0.138, weight of timeliness: 0.185, weight of tracking and tracing: 0.174.

Example 2 (E2): Here is an example from the study of Özekenci *(2025): weight of customs: 0.170, weight of infrastructure: 0.155, weight of international shipments: 0.175, weight of logistics competence and quality: 0.153, weight of timeliness: 0.165, weight of tracking and tracing: 0.182."*

CoT

"There are six criteria: Customs, infrastructure, international shipments, logistics competence and quality, timeliness, tracking, and Tracing. You are required to assess the weights of each criterion."

Step-by-Step Analysis

Step 1: Do you think these criteria are equally important?

Step 2: What is the most important criterion?

Step 3: What is the least important criterion?

Step 4: Please rank the criteria from the (most important one) to the (least important one).

Step 5: Please determine weights to show the importance of each criterion. The results of each criterion should be between 0 and 1. In addition, the sum of all weights should be 1.

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Post-prompt part:

PP1: *"Is there any other criterion you can advise to measure the logistics performance?"*

PP2: *"Do you think (Cx) is more important than (Cy)?"*

4. Results

In this study, there are two decision makers (DM1 and DM2), three prompting types (zero shot, few shot, and CoT), and two sub-types in few shot (E1, E2). As a result, eight different weights were determined using ChatGPT, as shown in Table 4. Table 5 is derived from Table 4 to make it easy to see the ranking.

In the DM1 CoT Step-by-Step analysis, since ChatGPT gave the ranking at the end of the answer Step 3, Step 4 was skipped. In the DM2 CoT Step-by-Step analysis, since ChatGPT gave the ranking at the end of the answer Step 2, Step 4 was skipped. To analyze consistency, the Step 3 prompt was applied, and the "infrastructure" answer was verified.

Table 4: ChatGPT-based weights of LPI criteria

	DM1 Zero shot	DM1 Few shot E1	DM1 Few shot E2	DM1 CoT	DM2 Zero shot	DM2 Few shot E1	DM2 Few shot E2	DM2 CoT
C1	0.15	0.130	0.160	0.120	0.15	0.14	0.16	0.12
C2	0.20	0.180	0.170	0.190	0.20	0.13	0.15	0.08
C3	0.15	0.200	0.165	0.140	0.15	0.22	0.18	0.22
C4	0.20	0.160	0.155	0.180	0.20	0.14	0.15	0.15
C5	0.15	0.170	0.180	0.210	0.20	0.18	0.16	0.25
C6	0.15	0.160	0.170	0.160	0.10	0.19	0.20	0.18

Table 5: Rankings of LPI criteria

DM1 Zero shot	DM1 Few shot E1	DM1 Few shot E2	DM1 CoT	DM2 Zero shot	DM2 Few shot E1	DM2 Few shot E2	DM2 CoT
C2-C4	C3	C5	C5	C2-C4-C5	C3	C6	C5
-	C2	C2-C6	C2	-	C6	C3	C3
C1-C3-C5-C6	C5	-	C4	-	C5	C1-C5	C6
-	C4-C6	C3	C6	C1-C3	C1-C4	-	C4
-	-	C1	C3	-	-	C2-C4	C1
-	C1	C4	C1	C6	C2	-	C2

DM1 results

Table 4 shows the results for DM1:

- "Infrastructure (C2)" and "logistics competence and quality (C4)" are slightly more weighted in the answer to the "DM1 Zero shot" prompt.
- "International shipments (C3)" received the highest weight in the answer to the "DM1 Few shot E1" prompt.
- "Timeliness (C5)" received the highest weight in the answer of "DM1 Few shot E2" prompt.
- The answers of "DM1 CoT" are step-by-step
- Step 1 (Prompt asking for opinion about equal weight): *"Six criteria are not equally important …….. Factors like timeliness, infrastructure, and logistics competence typically deserve higher weights due to their cross-cutting and direct impact on logistics performance. Customs and international shipments are context-dependent; their weight should reflect a country's or industry's trade orientation. Tracking and Tracing is gaining importance with digitalization and rising customer expectations, but still ranks just below core physical enablers."*
- Step 2 (prompt asking for most important criterion): The most important criterion is "Timeliness (C5)"
- Step 3 (prompt asking for the least important criterion): The least important criterion is "Customs (C1)" and the ranking is in Table 5.
- Step 4 (prompt asking for ranking): Skipped
- Step 5 (prompt asking for weights): The weights are listed in Table 4.
- PP-1 (prompt asking for additional criteria): Additional criteria proposed by ChatGPT are *"supply chain resilience, sustainability/green logistics, cost efficiency, inventory management effectiveness, technology adoption, and last-mile delivery (optional)."*

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- PP2 (prompt asking for consistency check): The answer for the prompt "Do you think 'international shipments' is more important than 'tracking and tracing"? Was "*No, tracking and tracing is generally more important than international shipments."*

DM2 results

Table 4 also shows the results for DM2:

- "Infrastructure (C2)", "logistics competence and quality (C4)", and "Timeliness (C5)" are slightly more weighted in the answer of "DM2 Zero shot" prompt.
- "International shipments (C3)" received the highest weight in the answer to the "DM2 Few shot E1" prompt.
- "Tracking and tracing (C6)" received the highest weight in the answer to the "DM2 Few shot E2" prompt.
- The answers of "DM2 CoT" are step-by-step
- Step 1 (Prompt asking for opinion about equal weight): *"From my 10 years of experience in logistics, I would say these six criteria are not equally important—each plays a distinct role and impacts overall logistics performance differently…….…... Operational and service-related criteria like International Shipments, Timeliness, and Logistics Competence & Quality tend to carry higher weight because they directly affect supply chain performance and customer satisfaction. Structural and regulatory criteria like Customs and Infrastructure are essential but usually more stable or long-term focused. Tracking and Tracing are growing in importance as visibility becomes a key competitive advantage. If the criteria were equally weighted (each ~0.167), it would oversimplify the complex reality and potentially misrepresent the real drivers of logistics performance."*
- Step 2 (prompt asking for most important criterion): The most important criterion is "Timeliness (C5)" and the ranking is in Table 5.
- Step 3 (prompt asking for the least important criterion): The least important criterion is "Infrastructure (C2)"
- Step 4 (prompt asking for ranking): Skipped
- Step 5 (prompt asking for weights): The weights are listed in Table 4.
- PP-1 (prompt asking for additional criteria): Additional criteria proposed by ChatGPT are "*cost efficiency, flexibility and responsiveness, sustainability / environmental impact, safety and security, customer service/satisfaction, inventory management efficiency".*
- PP2 (prompt asking for consistency check): The answer for the prompt "Do you think 'international shipments' is more important than 'tracking and tracing"? *Whether International Shipments is more important than Tracking and Tracing really depends on the context of the logistics operation, but here's how I see it from my experience: In traditional trade-focused logistics, International Shipments is often weighted higher. In highly digitized or customer-focused logistics, tracking and Tracing may take precedence."*

5. Discussion

This section delves into the discussion of the results after the experiments via designed prompts with ChatGPT. The answers of "DM1 Zero shot" and "DM2 Zero shot" prompts were nearly the same, except "Timeliness (C5)" got the highest weight in the answer of "DM2 Zero shot" prompt. Indeed, there is not a huge difference between "supply chain director" and "academician" roles. On the other hand, the answer of "DM1 Zero shot" concludes with *"Let me know if you'd like to adapt this for a specific country or industry context,"* while the answer of DM2 Zero shot concludes with "*Would you like me to adjust weights for a particular region, sector, or type of logistics operation? Or, if you want, I can provide a quantitative method (like AHP or entropy weighting) to calculate these weights systematically."* This shows the importance of role definition.

The most important criterion is "International shipments (C3)" in both of the answers of "DM1 Few Shot E1" and "DM2 Few Shot E1". The idea behind the change of the highest weighted criterion is obviously the example given, because in E1, "international shipments (C3)" has the highest weight. This situation changes in the "Few-Shot E2" prompt. The answer to the "DM2 Few Shot E2" prompt is the same as E2, with "Tracking and tracing (C6)", but "Timeliness (C5)" in "DM1 Few Shot E2". The ranking is also nearly consistent with "DM2 Few Shot E1" and "E1," but "DM1 Few Shot E1" is different. On the other hand, the ranking is nearly consistent with "DM2 Few Shot E2" and "E2". "DM1 Few Shot E2" is different again. This result shows that the answers of the academician role (DM2) are more similar to the example, which is also an output of an academician. The idea behind the similarity of the ranking is probably the role similarity.

The highest weight is "Timeliness (C5)" in both "DM1

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CoT" and "DM2 CoT," but the other weights are not aligned with it. The answer of "DM2 CoT PP2" also needs to be interpreted by an expert.

When the obtained results are compared with the values in Table 2 and Table 3 (literature review), it is seen that DM2, Few Shot E2, and Özekenci (2025) AWM results are similar, except for equal weights in ChatGPT results. This similarity comes from the fact that the E2 data obtained from Özekenci (2025) are AWM results.

On the other hand, the results of DM2 CoT and Mesic (2022) are similar except for equal weights in ChatGPT results.

6. Conclusion

LPI is an important indicator in the logistics sector performance evaluation. MCDM usage in the evaluation of logistics performance is quite common. The emergence of LLMs in the MCDM research area is expressed as a "revolution" (Wang et al., 2025) on the one hand and stated just a "significant innovation" (Dehghanimohammadabadi and Kabadayi, 2025) on the other hand. In this context, the competency of ChatGPT as a virtual expert was demonstrated with various research studies (Wang and Wu, 2024) in the literature. It is aimed to analyse the suitability of ChatGPT as an LLM to produce weights used for MCDM techniques. Eight types of prompts were designed, and weights were obtained. The results were compared with the literature. Results show that although there is an opportunity, there are also some concerns that need to be taken into consideration, as explained in the Discussion part. These concerns are consistent with Frederico's (2023) statement: "*Technology cannot completely replace the practitioners' ability in the decision-making process in supply chains*".

7. Theoretical and Practical Implications

The findings of this study-are beneficial for researchers in the MCDM area who want to integrate LLMs in the field and researchers in logistics performance evaluation in terms of theoretical implications. On the other hand, in terms of practical implications, this study will help not only the professionals in the logistics sector but also the beginners to give insight into the criteria and their importance in logistics performance.

8. Limitations

As in all studies, there are some limitations in this study. The limitations are organized in five main parts and bullets in each part below:

Limitations of LLM

- The first limitation is using only ChatGPT as an LLM. There are some challenges and ethical issues in the literature about ChatGPT that can be considered as limitations of the study (Ray, 2023): Reliability and accuracy, overreliance on AI, quality control, dataset bias, generalization, explainability, energy consumption, real-time responsiveness, safety and privacy concerns, cultural and linguistic bias, adapting to domain-specific knowledge, adversarial attacks, misinformation, autonomy, human-like interactions are some of them. It is highly important to listen to the warnings of Park et al. (2025) regarding limitations (draft-level quality of code generation, handling data complexity, and computational performance) of LLM-based MCDM models.
- In addition, literature put forth the risk of hallucination in LLMs (Park et al., 2025). Not using a pretrained model and a fine-tuning strategy in this study increases this risk.

Limitations of the reference model

- Using the LPI index to measure logistics performance.
- In addition, only the six criteria are predefined according to the LPI index. Post-prompt results in this study show that new criteria can be added to the reference model.

Limitations of the MCDM side

- Using only two decision makers is a limitation of this study.
- In the current CoT type prompt, it is not known whether ChatGPT used an MCDM technique like the Best-Worst method (Rezaei, 2015) or not.
- In addition, as can be seen in the Discussion part, comparison with other MCDM techniques in the literature can not be made exactly due to the equal weights obtained with ChatGPT.

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Limitations of the experiment design

- It was determined that three factors (decision maker number with two levels, prompt type with three levels, and few-shot type with two levels) were used in the experiment design.

Limitations of the prompt design

- As it is stated by Ray (2023), to meet specific needs using ChatGPT, one needs to gain experience in writing prompts. Due to it is the first attempt of the author(s), lack of experience is a limitation of this study.

Future Research

Based on the aforementioned limitations, future research suggestions are organized in five main parts and bullets in each part below:

Future research about LLM

- There are other LLMs, rather than ChatGPT, that can be used and compared in future studies. Comparing the results of Wang et al. (2025) with those of other open-source LLMs or other commercial models can be a research avenue. In addition, domain-specific AI language models can be developed and used to ensure more relevant, accurate, and in-depth information (Ray, 2023).
- To reduce the risk of hallucination, it is advised to pretrain or fine-tune the model (Park et al., 2025).
- To use the potential of ChatGPT effectively, it is also advised to collaborate with human experts (Ray, 2023).

Future research about the reference model

- There are other indices, other than the LPI index, used to measure logistics sector performance, such as the Agility Emerging Markets Logistics Index (AEMLI) (Kara et al., 2025). Criteria in this index can be weighted with LLMs in future studies and can be compared with LPI index results.
- In addition, LLMs can be used to develop a new index to measure logistics performance with its own criteria.

Future research about the MCDM side

- The number of decision makers can be increased in future studies.
- It is possible to improve the explainability of ChatGPT by using additional post-prompts to learn the algorithm behind it. In this algorithm, the normalization procedure and also calculations/ statistical methods need to be taken into account.
- We used a ranking-based approach in this study. Using a pairwise comparison-based approach will be a research avenue.
- Longitudinal studies (Çıray et al., 2024) and a standardised approach for using LLMs in AHP modelling (Park et al., 2025) are other examples in the literature.
- There is also a need to entitle this emerging research area. AIDM (AI-Driven Decision Making) (Dehghanimohammadabadi and Kabadayi, 2025) is too broad, and ChatGPT-based MCDM (Wang and Wu, 2024) is too narrow. Due to this, "LLMs-based MCDM" is offered. This suggestion is also debatable.

Future research about the experiment design

- Experiment design can be redefined using different factors and levels in each factor. In role determination, different expertise levels (15 years/ 20 years, etc.) or genders (male/female) can also be added.

Future research about the prompt design

- Prompts can include sector, country, etc.
- The framing effect can also be checked with prompt designs
- Prompts can be revised not to produce equal weights.
- The proposed prompts can be applied in different contexts (e.g., healthcare, etc.) in future studies.
- The results can be compared using some statistical techniques.
- On the other hand, energy and water consumption are increasing depending on the number of prompts. Because of this concern, 18 prompts were used. Last but not least, it is very important to report the number of prompts in this kind of study as a performance criterion.
- While literature reports the accuracy rate increases with few-shot prompts, it is foreseen that this prompt style can cause biases and subjectivity problems in the MCDM weighting area. Due to the lack of information on the number of digits in prompts, nearly half of the results contain two digits after zero. To improve accuracy, adding the output style can be beneficial.

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Declaration of Generative AI in Writing

The author has used the ChatGPT free version while preparing this article to obtain weights of LPI criteria, to ask alternative criteria, and to check consistency on 30.05.2025.

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Machine Learning-Driven Prediction of Cost-Efficient Shipping Lines: Evidence from Freight Forwarding Operations

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Abstract

Purpose: *This research evaluates the performance of various machine learning models in forecasting cost-efficient transportation lines from the viewpoint of freight forwarders. It addresses the requirement for data-informed decision-support tools that can enhance the precision of shipment line selection.*

Design/Methodology/Approach: *A dataset comprising 983 shipment records from 37 freight-forwarding companies in Egypt was examined. Six machine learning models, Naive Bayes, K-Nearest Neighbour, Support Vector Machines, Decision Trees, Random Forests, and Neural Networks, were trained and assessed employing an 80/20 train-test partition. The performance of the model was evaluated utilizing accuracy, precision, recall, and F1-score.*

Findings: *Random Forests and Decision Trees achieved the finest predictive performance, with accuracy scores of 0.83 and 0.80, respectively. K-Nearest Neighbour exhibited moderate performance, whereas Naive Bayes and Neural Networks demonstrated comparatively lower predictive accuracy. Support Vector Machines demonstrated suboptimal performance across all evaluated metrics. The findings suggest that ensemble and tree-based methodologies are highly appropriate for modeling the cost efficacy of shipping lines.*

Research Implications/Limitations: *The research emphasizes the significance of model selection in logistics forecasting tasks and demonstrates that more complex or computationally demanding models do not necessarily surpass the performance of simplified tree-based approaches. The dataset is restricted to shipments originating from Egypt in 2022, which may impact its overall generalizability.*

Practical Implications: *The findings provide freight forwarders with a foundation for incorporating machine learning into their operational decision-support systems. Utilizing Random Forests or Decision Trees can improve the precision of shipping line selection, lower expenses, and facilitate data-driven logistics planning.*

Originality: *The study offers a comparative analysis of various machine learning methods specifically applied to the selection of transportation lines, a subject with limited prior exploration. It provides empirical evidence on the predictive models that most effectively aid in making freight-forwarding decisions related to cost efficiency.*

Keywords: *Cost-effective shipping lines; Decision Trees; Freight forwarding; Machine learning; Predictive modelling; Random Forests; Shipping line selection*

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1. Introduction

In the global logistics network, freight forwarding is essential. Establishing a connection between the shipper and the carrier guarantees that international cross-border shipments reach their destinations effectively and efficiently, that is, in a timely and economical manner (Ho *et al.*, 2017; Dzakah Fanam, Nguyen, and Cahoon, 2018). Selecting the best shipping line is a crucial strategic choice that forwarders must make for every cargo in this dynamic global environment, where there are numerous routes from point A to point B. This will guarantee high operational efficiency and a competitive edge. When making such a crucial choice, freight forwarders need to consider many aspects, including carrier reliability, transit times, and service charges (Ho *et al.*, 2017; Dzakah Fanam, Nguyen, and Cahoon, 2018; Ergin and Alkan, 2023).

The logistics and supply chain management field is now reaping the benefits of machine learning (ML), a key emerging technology with the potential to reveal complex patterns within large datasets and forecast the best logistical choices. It has a variety of models, and the field has not yet settled on which one or ones work best for predicting cost-effective shipping routes. This research examines six prominent machine learning models: Naive Bayes, K-Nearest Neighbor (KNN), Support Vector Machines (SVM), Decision Trees, Random Forests, and Neural Networks, and evaluates their comparative effectiveness in predicting cost-effective shipping line selection. These models were selected to represent probabilistic, distance-based, margin-based, tree-based, ensemble, and non-linear learning paradigms.

The Egyptian freight market in 2022 was very unstable on a macroeconomic level, with currency devaluations, changing freight rates, and limits on foreign currency. This made it impossible to choose a shipping line based on traditional heuristics, so machine learning-based decision-support systems had to be put in place. While evidence exists regarding the effectiveness of machine learning in various logistics applications, the existing literature lacks comprehensive research assessing the predictive capabilities of ML algorithms for real-time, cost-efficient shipping line selection from the perspective of freight forwarders. This study addresses the gap by employing diverse machine learning models to identify the principal cost factors influencing freight forwarders' shipping line selection and to precisely forecast optimal decisions, thereby providing the data-driven framework essential for practitioners to make systematic choices in unstable contexts.

The goal of this study is to determine how well various machine learning models perform in terms of prediction. From the perspective of a freight forwarder, these forecasts relate to integrating economical shipping line options into a logistics decision-support system.

The following research question serves as the study's guide: Which machine learning models are the most effective at predicting cost-effective shipping lines?

2. Related Work

Related works on this topic have two research streams. The following sections review the related works on freight forwarding. The next stream investigates the research on using machine learning in freight forwarding. Finally, a shipping line selection from the perspective of a freight forwarder.

2.1 Freight Forwarding

Freight forwarding services play a vital role in the international trade and commerce setup, allowing for the movement of goods from one place to another with precision, efficiency, and cost-effectiveness. Freight forwarding services. According to the International Federation of Freight Forwarders Associations (FIATA):

"Freight Forwarding Services means services of any kind relating to the carriage, consolidation, storage, handling, packing or distribution of the Goods as well as ancillary and advisory services in connection therewith, including but not limited to customs and fiscal matters, declaring the Goods for official purposes, procuring insurance of the Goods and collecting or procuring payment or documents relating to the Goods." (FIATA, 2019)

The services of a freight forwarder include the following: the management of shipping routes, customs operations, documentation, storage, and distribution of goods. These intermediaries facilitate the link between shippers and carriers, promoting seamless and timely movement of products across international borders (Ding *et al.*, 2017; Huang, Bulut, and Duru, 2019).

Freight forwarding requires a deep understanding of global trade complexities, including navigating various international regulations and procedures. Research indicates that freight forwarders significantly contribute

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to optimizing supply chains by selecting the most efficient shipping routes and facilitating smooth cross-border trade (Rajasekar and Prabhakar, 2015).

Their role is important in the liner shipping industry because they represent the most frequent customer of the shipping lines. Hence, their criteria for carrier selection are paramount in defining winners and losers in the marketplace. Typically, forwarders would pay special attention to various elements when picking shipping lines: freight rates, adherence to schedules, reliability in service, door-to-door services, and environmental performance (Dzakah Fanam, Nguyen, and Cahoon, 2018).

2.2 Machine Learning in Freight Forwarding

Machine learning enables systems to improve performance by learning from past data. This added sophistication in data analytics is through the kind of algorithms that learn from patterns, adjust with new data, and keep perfecting their predictions. This is beneficial for handling large datasets or situations in which the data is too complex for conventional statistical methods (Rao, Chandra, and Kumar, 2017).

The use of machine learning in logistics and freight forwarding has greatly transformed these sectors. Machine learning empowers systems to learn from data, thus improving predictive accuracy over time. This combination is highly effective at solving complex logistic problems; among them, there are predicted demand (Ermagun *et al.*, 2020), optimizing shipping routes (Cao, 2022), and reducing operational costs (Gkerekos, Lazakis, and Theotokatos, 2019).

The studies (Cao, 2022) and (Sert *et al.*, 2020) also found that the combination of data analytics and machine learning in logistics for task automation, even in such simple tasks as tracking of shipments and route planning. This not only increases efficiency but also raises the satisfaction level among the clients. It was found that companies implementing machine learning models can reduce delivery time and operational costs by real-time insights into automation of decision-making and freight forwarder performance.

The table delineates global machine learning applications in freight forwarding. It highlights both established research domains and notable knowledge deficiencies. Studies originate from developed economies like the USA, the Netherlands, and Portugal, with scant contributions from emerging markets, including Indonesia and Poland. Notably, there exists a substantial gap in research on critical logistics hubs and developing economies, such as China, India, North Africa, and the Middle East. In Table 1, different machine learning techniques are presented, encompassing options like Naive Bayes and linear regression, together with Bayesian Nonparametric structures. The research covers various aspects of freight forwarding activities, including risk assessment, fraud detection, personnel performance forecasting, traffic management, and cost and time evaluations.

Table 1. Machine Learning Applications in Freight Forwarding

#	Paper	Application Country	ML Technique	Prediction Area
1	(Shang, Dunson, and Song, 2017)	Global	Bayesian Nonparametric (Probit Stick-Breaking Process mixture model)	Risk Assessment in Air Cargo Transport
2	(Cyperski, Okulewicz and Domański, 2024)	Poland	Hybrid Approach: DBSCAN, k-NN, XGBoost	Cost Estimation for Full Truckload (FTL) Shipping
3	(Triepels, Feelders and Daniels, 2015)	Netherlands	Probabilistic Classification: Naive Bayes (NB), Tree-Augmented Naive Bayes (TAN)	Document Fraud Detection in Maritime Freight
4	(Calixto and Ferreira, 2020)	Portugal	Naive Bayes Classifier	Salespeople Performance
5	(Hathikal, Chung, and Karczewski, 2020)	USA	Multinomial Logistic Regression, Decision Tree, KNN, SVM	Shipment Lead Time for Ocean Freight
6	(Wahyudi and Septya Arroufu, 2022)	Indonesia	Linear Regression	Delivery Time Prediction
7	(Bridgelall, 2024)	USA	Data Mining and GIS-based Analysis	Freight Traffic Reduction
8	(Birkel, Kopyto, and Lutz, 2020)	Germany	NA	Capacity forecasting, resource allocation
9	(Jang, Chang, and Kim, 2023)	Republic of Korea	LightGBM, XGBoost, DNN, MLR	Cost prediction for freight shipping

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Taken together, Table 1 highlights a pronounced empirical gap in machine learning applications for freight forwarding within developing economies, particularly in volatile markets such as Egypt, a gap that the present study directly addresses by providing evidence from a real-world 2022 Egyptian freight forwarding dataset.

2.3 Shipping Line Selection

To achieve the best possible results, freight forwarders must perform a careful evaluation of the shipping lines they utilize. They consider many aspects of a shipping company over which that company has direct control. First, and most important, is the aspect of price. The freight rates a shipping line offers directly impact both the forwarder and the forwarder's customer. The second major aspect, service reliability, is equally crucial. Price advantages can mean little to a forwarder and its customer if the service that the forwarder is paying for is unreliable. Service reliability encompasses both the ship's performance (arriving on time and in good condition) and the performance of the shipping line's staff at both ends of the journey. After price and service reliability comes the matter of transit time. These factors significantly affect forwarder efficiency and client satisfaction (Lukinskiy and Lukinskiy, 2015; Ho *et al.*, 2017; Dzakah Fanam, Nguyen, and Cahoon, 2018; Ergin and Alkan, 2023).

3. Methods

3.1 Data Description

The dataset used in this study includes 983 shipment records collected from 37 freight forwarding businesses operating in Egypt, encompassing a wide range of shipment characteristics such as service cost, cargo type, port of loading, port of discharge, importer country, and shipping line. The data covers the year 2022 and includes significant elements crucial to the decision-making process for choosing shipping lines.

Table 2 lists these features and describes them.

Table 2. Summary of Dataset Features and Descriptions

Feature	Description	Type
Cargo	Type of cargo being transported	Qualitative
Industry	Industry associated with the cargo	Qualitative
Port of Loading	Departure port for the cargo	Qualitative
Port of Discharging	Arrival port for the cargo	Qualitative
Importers Countries	Countries where the importers are located	Qualitative
Service Cost (USD)	Cost of service per tonnage in USD	Quantitative
Shipping Line	Name of the shipping company	Qualitative

The data cleaning process involved handling missing values, removing outliers, and standardizing the service cost to a common currency using the Central Bank of Egypt's exchange rates. Additionally, new features such as Service Cost per Tonnage were engineered to improve model accuracy.

3.2 Model Training and Evaluation

Six machine learning models, Naive Bayes, K-Nearest Neighbor, Support Vector Machines, Decision Trees, Random Forests, and Neural Networks, were trained and evaluated using an 80/20 train–test split. The following evaluation metrics were used to compare model performance:

- Accuracy: The expression of the ratio of correctly predicted observations to total observations (Tohka and van Gils, 2021).
- Precision: The ratio between true positive predictions and the total amount of positive predictions (Hicks *et al.*, 2022).
- Recall: The ratio between correctly classified positive samples and all samples assigned to the positive class (Tohka and van Gils, 2021; Hicks *et al.*, 2022).
- F1-Score: The harmonic mean of precision and recall, providing a balanced measure of model performance (Tohka and van Gils, 2021; Hicks *et al.*, 2022).

4. Results

This study's main goal is to assess how well various machine learning models perform when it comes to predicting shipping selections from a cost perspective for a freight forwarder. The models used were Naive Bayes, K-Nearest Neighbour, Support Vector Machines, Decision Trees, Random Forests, and Neural Networks. They were trained on a dataset of 983 shipment records, and then their performances were compared using four key metrics: accuracy, precision, recall, and F1-score.

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The figure below shows the performance metrics of each model:

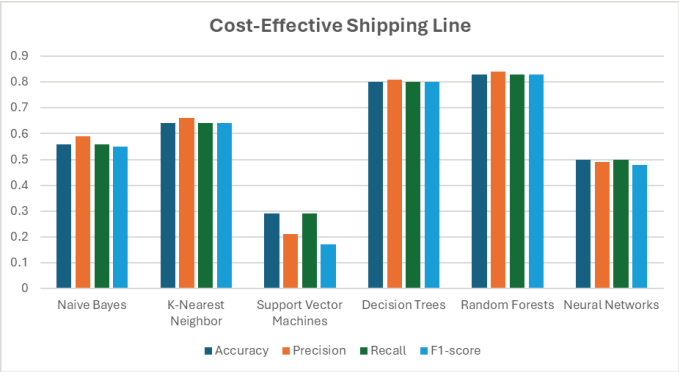

Figure 1: Performance metrics for Cost-Effective Shipping Line Prediction

4.1 Naive Bayes Performance

The Naive Bayes model has a consistent but moderate performance across all metrics in predicting shipping lines that are cost-effective. Its accuracy is just 0.56, which amounts to a correct prediction in only 56% of cases, indicating only a fair ability to make accurate predictions. Its precision score of 0.59 indicates that it's not the class of cost-effective shipping lines that has been identified as cost-effective; rather, it's nearly 41% of the time that we've encountered false positives. Finally, when we look at recall, we can capture only a moderate proportion of the actual cost-effective shipping lines. Combined with its F1-score of 0.55, which represents a balance of precision and recall, the model provides an average result. In summary, Naive Bayes ranks as one of the least effective models within this analysis. Its inability to deliver high accuracy and reliable predictions makes it unsuitable for supporting high-quality logistics decision-making, particularly in contexts where minimizing errors is critical.

4.2 Support Vector Machines Performance

The Support Vector Machines (SVM) Method proved less efficient with values oscillating from 0.17 to 0.29. Its accuracy of 0.29 means that we got the predictions correct only in 29% of the cases. This came with a precision score of 0.21, implying that the false positive rate is 79%, an alarming figure, along with an abysmal F1-score of 0.17, which again consolidates its ineffectiveness overall. This analysis indicates that performance is extremely bad with the SVM model; all metrics, particularly accuracy, precision, recall, and F1-score, are significantly less than 0.5, which is a clear indication of very poor performance. It indicates that SVM struggles very much to distinguish low-cost shipping lines, so it misclassifies them a lot. These low metrics indicate that SVM is not appropriate for this logistics application because its predictions misclassify too many shipping line costs.

4.3 K-Nearest Neighbor (KNN) Performance

In our assessment of economic shipping lines, the K-Nearest Neighbor (KNN) algorithm surpassed Support Vector Machines. With an accuracy of 64%, KNN uses a distance-based approach that is more suitable for this dataset, but it also shows potential for enhancements. KNN's precision is 0.66, which means that we can have a certain level of trust in about two-thirds of the identified cost-effective shipping lines, certainly an improvement over Support Vector Machines, but still risky in terms of false positives. KNN's recall is 0.64; it recognized two-thirds of the true cost-effective shipping lines, which I suspect also represents a slight improvement over the recall of our previous model.

The KNN algorithm is good at identifying the correct class for positive instances, albeit it does include some false positives in the result. Its F1-score of 0.64 indicates that the KNN algorithm has a moderate balance of precision and recall. It is a good algorithm to use in contexts where we are slightly okay with identifying some negative instances as positive (false positives) and identifying some positive instances as negative (false negatives). It has an intermediate performance across all the metrics we considered in our analysis, making it a reasonable choice for solving uncomplicated, low to medium complexity logistics decisions. On the other hand, KNN is sensitive to data scaling and not the best algorithm if you put priority on computational requirements.

4.4 Decision Trees Performance

The Decision Tree model demonstrated strong predictive capability by achieving an accuracy of 80%. Its strength lies in its transparent, rule-based structure, which enables the model to capture non-linear relationships between shipment attributes such as cargo type, ports, and service cost.

With a precision of 0.81, the model reliably distinguished cost-effective shipping lines while maintaining a manageable false-positive rate. The recall score of 0.80 further indicates that the Decision Tree successfully identified most genuinely cost-efficient alternatives.

A key advantage of the Decision Tree model is interpretability. Unlike more complex models, their decision paths can be directly examined and translated

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into operational decision rules, making them particularly suitable for freight forwarders seeking both accuracy and managerial transparency.

4.5 Random Forests Performance

Random Forests outperformed all other models, achieving the highest accuracy of 83%. By aggregating predictions from multiple decision trees trained on randomized feature subsets, the model mitigates overfitting and improves generalization performance.

The model's precision (0.84) and recall (0.83) indicate superior stability and robustness compared to a single Decision Tree, particularly in handling noisy and heterogeneous freight forwarding data.

While Random Forests sacrifice some interpretability due to their ensemble structure, this limitation is offset by their enhanced predictive reliability. For operational decision-support systems prioritizing accuracy over explainability, Random Forests represent the most effective modeling choice in this study.

4.6 Neural Networks Performance

In our assessment of the most cost-effective shipping lines, the Neural Networks model demonstrated intermediate performance across all evaluated metrics. The accuracy of Neural Networks is 0.5, which indicates that the model correctly identified half of the cost-effective shipping lines. This is a significant drop compared to the leading models, such as Decision Trees and Random Forests.

The precision of Neural Networks is about 0.49, which means that there is a 49% chance that the model will correctly identify cost-effective shipping lines among its positive predictions. This, however, really means that there is a huge risk of false positives, and while attending to the predictions made by this model, it is still a very cautious and restrained approach.

As for the recall, Neural Networks scored 0.5, meaning that the model could classify correctly only fifty percent of actual cost-efficient shipping lines. This result indicates the need for improvement, especially if it is to reduce missed opportunities in logistic decision-making.

An F1-score of 0.48 suggests that Neural Networks hardly achieve an optimal balance between precision and recall, as the interaction between both is only moderate. It also means that while Neural Networks can handle some logistic predictions, they are not the most reliable choice for the presented dataset without further tuning.

In general, Neural Networks show a performance that is relatively moderate and less impressive compared to alternatives such as Decision Trees or Random Forests. While the adaptability and capacity of the model for improvement are considerable, it is currently more suitable for scenarios where high computational costs are tolerable and where a moderate level of accuracy is acceptable. To obtain better results for logistics decisions, Neural Networks might require more training, optimized parameters, and data scaling.

5. Discussion

A general look at the effectiveness of different predictive models towards cost-effective shipping line forecasts finds Random Forests and Decision Trees the most effective and beneficial predictive models. Such pronounced, clear superiority in their performance on a wide range of evaluation metrics outlines their status as reliable tools for freight forwarding companies' decision-makers. The great capability of these models to handle complex interactions with several variables, and their built-in robustness when dealing with highly diversified data sets, especially equips them for characteristics in freight operations that are always evolving (Gkerekos, Lazakis, and Theotokatos, 2019).

The superior performance of tree-based models can be attributed to their ability to natively handle categorical variables and complex feature interactions without requiring extensive preprocessing. Freight forwarding datasets typically include high-cardinality categorical attributes such as ports of loading, ports of discharge, cargo types, and shipping lines. Tree-based methods efficiently partition such feature spaces, whereas distance-based models like KNN and margin-based models such as SVM struggle with mixed data types and complex distance relationships.

5.1 Interpretation of Results

From the machine learning analysis done on the adoption of various models, such as Random Forests, Decision Trees, and K-Nearest Neighbor (KNN), on the historical shipment dataset, the shipping line choice was extrapolated. Key findings are given below:

- The best models for predicting cost-effective shipping lines were Random Forests and Decision Trees. These models had remarkably high accuracy and recall scores, with Random Forest achieving an accuracy of 0.83, while Decision Trees scored 0.8 for cost-effective shipping line predictions.

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- K-Nearest Neighbor ranks third, with moderate performance and metrics around 0.63-0.65; this is a much bigger drop from the tree-based methods, but continues in terms of consistency of performance overall metrics.
- Naive Bayes comes fourth in the ranking, with a lower performance score but consistent on most measures (at around 0.55), indicative of slightly dependable predictive capabilities.
- Neural Networks come in fifth, with a performance that is rather modest, at about 0.50, which is surprising and disappointing given their usual prowess in many other areas.
- Interestingly, the performance of Support Vector Machines (SVM) in general average was underperformed, in predicting cost-effective shipping lines, suggesting that models like random forests, decision trees, and, to a lesser extent, the K-nearest neighbor model were best suited to dealing with the complexities of shipping data.

Machine Learning enables predictive analysis that helps a logistics manager anticipate cost efficiency across different shipping lines. These findings underscore the value of integrating data-driven decision-making into logistics management for optimizing both operational efficiency and competitiveness.

5.2 Practical Implications for Freight Forwarders

The findings from this study provide valuable insights for freight forwarders seeking to optimize their shipping line selection processes:

- Understanding how to use and integrate Random Forests and Decision Tree models into their decision-support systems can benefit freight forwarders. Doing so will help them predict with high accuracy the most cost-effective shipping lines and, in turn, will help them create additional decision rules that make digesting their complex data into complex yet simple enough insights that are actionable.
- Using machine learning models enables freight forwarders to make important decisions based on more than just tradition and experience. They allow for the analysis of vast quantities of data and can improve decision-making. They provide for the kind of operational excellence that can lead to cost savings and improved efficiency.

5.3 Comparison with Existing Literature

The current research investigates the application of machine learning in the decision-making process, particularly concerning selecting a shipping line that is cost-effective. It offers a summary of how freight forwarders can arrive at palatable choices, affirming some theories while introducing new concepts to the field. The work is based on prior studies regarding data analytics and decision-making within the realm of logistics.

The results from the machine learning analysis confirm that cost-effective shipping line predictions can be made quite accurately using Random Forest and Decision Tree. This is consistent with a handful of studies (Ermagun *et al.*, 2020; Zhou *et al.*, 2023) that have found Random Forest and Decision Tree to be a good bet for predictions involving logistics outcomes. K-Nearest Neighbor demonstrates moderate performance, typically scoring between 0.5 and 0.7, indicating their potential as a cost-effective option (Kotenko, 2022). Support Vector Machines (SVM) show the lowest performance for all parameters (Uddin, Anowar, and Eluru, 2021). Nonetheless, the study's findings do suggest that if one is going to predict something related to logistics, one should opt for Random Forest and Decision Tree rather than either of the two algorithms mentioned above.

6. Conclusion

The shipping line selection problem of freight forwarders has a solid solution pathway through the usage of machine learning models. This study's primary focus was on determining the models' capabilities of identifying a cost-efficient shipping line choice. From a pool of four model candidates, the work uncovered the Random Forest and Decision Tree as the best performers and most reliable solution predictors. With more than an 80% accuracy score, the models cleanly pass through a freight forwarder's dataset of 983 shipment records.

To enhance the model's generalizability, the researchers recommend expanding the dataset to encompass a broader array of geographical regions and time periods. They also suggest using different machine learning techniques for yield improvement. This indeed is an area wide open to undertaking vast research and investigation into a very diversified array of alternative machine learning methodologies/techniques that shall, through future work research, greatly improve operational efficiency for the freight forwarding industry and its intricate decision-making processes in search of predictions which are not only more efficient but also,

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across a variety of shipping lines and routes, more accurate.

Given the operational disruptions observed in the Egyptian market during 2022, future research should extend the modeling framework to include transit time as a secondary target variable, as cost alone does not fully capture freight forwarders' decision priorities under conditions of congestion, currency volatility, and service unreliability.

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Does Technology Acceptance of Airport Self-service Engender Passenger Satisfaction with Airport Self-Service? Mediation Effect

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Abstract

Purpose: *Based on the Theory of Acceptance and Use of Technology (UTAUT), this Research aims to investigate which Performance Expectancy (PE) and Effort Expectancy (EE) affect Passenger Satisfaction indirectly through the mediating role of Propensity to Cross-Cultural Adaptation (PCCA).*

Design/ methodology/ approach: *The current study empirically examines this model using questionnaires administered to international passengers at Borg El Arab International Airport, as a strategic aviation hub in the Middle East and North Africa (MENA) region, known for its culturally diverse passenger base, by using covariance-based structural equation modeling (CB-SEM). Technologies are easy to understand and operate when these systems are. However, expecting technology to improve performance alone does not seem to affect satisfaction directly. The analysis also shows that the capacity to adapt to different cultural settings (PCCA) plays a key mediating role between both expectations and satisfaction. This means that cultural flexibility helps passengers turn their perceptions of usefulness and ease of use into actual satisfaction.*

Research implications/limitations: *This Research extends the Unified UTAUT by introducing a structural framework for travel environments that brings together people from diverse cultural backgrounds. The degree to which passengers accept and are satisfied with these technologies may depend on their personal views of the technology itself, as well as their ability to adapt across cultures.*

Practical implications/ limitations: *In practice, managers and system developers should not only focus on how effective or easy a system is but also consider cultural inclusiveness to raise satisfaction and promote more sustainable behavior among travelers.*

Originality: *By introducing this psychological model, the study expands the application of technology acceptance theory within aviation. It provides new insight from airports in emerging economies that could support Airport managers and technology designers to drive satisfaction.*

Keywords: *Smart airports; performance expectancy; effort expectancy; cross-cultural adaptation; passenger satisfaction; Alexandria Airport; Technology acceptance.*

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1. Introduction

Smart technology has become a global trend across the industry sectors, and airports are integrating digital technologies to improve the efficiency of their operational services, transforming the airport into a smart hub (Choi *et al.*, 2024). In recent years, the digital transformation has quickened, especially with global crises and sustainability pressures that prioritise contactless services and resource efficiency (Controls, 2019). For example, during the COVID-19 pandemic, airports had to adopt touchless self-service technologies (such as biometric check-in kiosks and e-gates) to minimise physical contact for the passengers to enhance their safety (Berti, 2020). That impact on the percentage of adopting smart technology in the airport, therefore, industry surveys report that, as of 2023, over 82% of airports have increased IT investments to deliver more seamless, personalised services, aligning with travellers' heightened expectations for convenient, sustainable journeys (Choi *et al.*, 2024). There is a growing concern about the role of smart airport technologies for improving passenger satisfaction and supporting sustainable aviation practices (Choi *et al.*, 2024).

The recognition of these benefits and how readily passengers accept and utilize the innovations introduced is raised. Notably, Many travelers, on one hand, appreciate self-service options that simplify procedures and reduce waiting time. On the other hand, some may experience travelers' hesitation or discomfort—particularly in airports with high cultural and linguistic diversity and constant passenger turnover (Yafi, Tehseen, and Haider, 2021). In this context, Alexandria International Airport in Alexandria, Egypt, provides a telling context in this matter. This airport serves as a significant link point among Africa, the Middle East, Asia, and Europe; therefore, travelers from diverse cultural and linguistic origins cross through there (Helmy, 2018). This cultural diversity often shapes visitors' interactions with smart technology, affecting their comfort and confidence in using it. With that in mind, these cultural norms are not taken into account. In that case, they may be reflected in differences in satisfaction levels across traveler groups.

The current study examines the impact of performance expectancy (PE), effort expectancy (EE), and cross-cultural adaptability (PCCA) on passenger satisfaction. PE, analogous to perceived usefulness in the Technology Acceptance (Robbins, 1964), reflects the degree to which a passenger believes that utilizing technology will enhance travel efficiency, such as by conserving time or improving the airport experience. Effort expectancy refers to the perceived ease of learning and use of self-service applications at airports (Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, 2003). Furthermore, both performance expectancy (PE) and effort expectancy (EE) are important indicators of user acceptance within the unified theory of technology acceptance (UTAUT) (Venkatesh *et al.*, 2003), which have been empirically used in many travel technology applications, including airline e-ticketing (Escobar-Rodríguez and Carvajal-Trujillo, 2023), biometric applications (Kim, Sung, and Lee, 2023), and airport self-check-in kiosks (Wongyai *et al.*, 2024). Therefore, The current study suppose that When travelers realize that a system saves them time and is easy to use, they are generally more likely to use it and feel more satisfied afterward, as a High PE (e.g., believing a self-check-in kiosk makes one's journey more efficient) and high effort expectancy (e.g., finding the kiosk easy to use) are generally associated with stronger intention to use and greater user satisfaction with the technology. Nevertheless, in an international airport setting, an intermediate variable may condition these relationships: PCCA is defined as a traveller's personal tendency or openness to adjust to different cultural environments and practices – in this case, adapting to unfamiliar technologies, languages, or customs encountered during travel (Wong, Sia and Ling, 2020).

Of note, recent academic discussions (Alexandra and Dias, 2024) have emphasized the need for models that better reflect the cultural diversity of modern mobility contexts. They argue that the PCCA model may serve as a crucial link between how travelers perceive technology and its outcomes. In response to these calls, this study presents an integrated model that links PE, EE, PCCA, and traveler satisfaction. Moreover, Florido-Benítez (2024 indicates that international travel environments require a combination of technological readiness and cultural flexibility (Florido-Benítez, 2024). They suggest that PCCA may be an important factor in shaping how people evaluate smart airport technologies. However, despite its importance, the PCCA model has received little attention in aviation-related technology acceptance research (Won, Chiu, and Byun, 2023). Recent academic discussions (Alexandra and Dias, 2024) have emphasized the need for models that better reflect the cultural diversity of modern mobility contexts. They argue that the PCCA model may serve as a crucial link between how travelers perceive technology and its outcomes. In response to these calls, this study presents an integrated model that links PE, EE, PCCA, and traveler satisfaction. This model extends the UTAUT framework by positioning the PCCA as a mediator that directs the impact of utility and usability expectations toward satisfaction. In a multicultural

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smart airport environment, simply perceiving a system as useful or simple (PE/EE) may not be sufficient to guarantee a positive experience; travelers must also be able to adapt to the cultural cues embedded in the technology itself. To test this hypothesis, the study draws on evidence from Alexandria Airport in Egypt. As smart airport initiatives are still in initial phases, they are gaining increasing momentum (Celemín-Pedroche, Ostomo, and Escat-Cort, 2023). Thus, the study contributes to existing literature in several areas of digitalization research. It adds a case study from Alexandria Airport—an environment combining newly introduced smart systems with a diverse passenger base (Khalaf, ASHOUR and Abdel Rady, 2023)—and moves beyond the traditional focus on large hub airports in West or East Asia (Sreenath, Sudhakar and Yusop, 2021; Eid *et al.*, 2022; Genina, Sakty and Ali, 2023). This answers calls for more scholarly attention to smart mobility in emerging markets and provides data on technology adoption in the Middle East/North Africa aviation context (Mohamed, Gomaa, and El-Sherif, 2018), which remains under-represented in academic Research (Mohamed, Gomaa, and El-Sherif, 2018; Bieliatynskyi *et al.*, 2022; Choi *et al.*, 2024). Moreover, by merging technological and human cultural factors, this study advances theoretical knowledge. It offers actionable insights for developing smarter, more inclusive, and sustainable airport systems (Choi *et al.*, 2024).

The remainder of the study is structured as follows. The next section presents literature reviews on smart airports. Then, the methodology section analysis results, including CB-SEM tables, are presented. Then discuss the implications of the findings, limitations, and future research directions before concluding.

2. Literature Review

2.1 Smart Airports and Sustainable Passenger Experience

The concept of "smart airports" applies to leveraging digital applications to deliver seamless travel (Rubio-Andrada *et al.*, 2023), depending on much information and communication technologies (ICT) and automation to make their operations more efficient, their services better, and their environmental impact smaller. Hence, technology is the enabler, but a technological individual's culture is what transforms automated facilities into performance. (Sugandha, Freestone, and Favaro, 2025). Unlike traditional airports, smart airports integrate systems such as self-service check-ins, biometric identity verification, real-time information delivery, and IoT-based asset management to create a seamless passenger journey(Mäkelä, 2024). Of note, the smart airport framework eliminates the need for physical check-in counters by using automated kiosks and e-gates, reducing paper waste and advancing environmental sustainability goals (Rupcic *et al.*, 2023). Williady, Handani & Kim (2024) have shown that airport service quality significantly shapes passengers' overall satisfaction and loyalty (Williady, Handani and Kim, 2024), by Avoiding delays, queues, and lost baggage through smart solutions can improve travellers' comfort and confidence. For instance, self-service baggage and check-in kiosks have been linked to higher traveler satisfaction, as these systems enable travelers to complete travel procedures at their own pace (Williady, Handani, and Kim, 2024). Notably, some research indicates that automation can have mixed effects: while efficiency and novelty can delight many passengers, the lack of human interaction may dissatisfy others who value personalized service (Al Sarrah, Ajmal, and Mertzanis, 2020; Eid *et al.*, 2024). In particular, cultural background can affect whether passengers prefer self-service or staff assistance (Simarmata *et al.*, 2025). The next subsections delve into these factors—PE and EE—and investigate the PCCA as a mediator of technology-driven satisfaction.

2.2 Performance Expectancy and Effort Expectancy in Technology Adoption

PE is defined as the extent to which travelers realize that using technology helps achieve gains in job or task performance (Simarmata *et al.*, 2025). In travel-related consumer settings, PE simply reflects how much people believe a service will actually improve their trip—whether by helping them save time, move more easily, or enjoy greater comfort. EE, on the other hand, is about how easy and straightforward the technology feels to use (Venkatesh *et al.*, 2003). These two ideas grew out of earlier concepts in the Technology Acceptance Model, which focused on perceived usefulness and ease of use (Davis, 1989). Despite the evolution of digital services, PE and EE remain among the strongest predictors of users' acceptance of a new system (Ursava, 2022). Of note, Research in tourism and transportation consistently highlights their importance. For instance, Escobar Rodríguez and Carvajal Trujillo (2014) used the UTAUT model to investigate the passengers' purchase intention of online airline tickets; they found that PE influenced purchase intention. When passengers felt the booking online platform offered better prices, faster booking, or simpler processes, they were more willing to purchase tickets from an airline's website (Escobar-Rodríguez and Carvajal-Trujillo, 2014). Likewise, EE (as ease of navigating the website) emerged as a significant predictor of intention. In airport settings, PE and EE have been shown to influence passengers' adoption of self-service technologies. A study (Lu *et al.*, 2024) on self-check-in kiosks found that perceived usefulness (PE) positively affected both usage intention

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and satisfaction, as passengers valued the efficiency gains (shorter check-in times, bypassing queues) (Choi *et al.*, 2024). EE, often operationalised as kiosk user-friendliness, also positively affected intention. If the check-in machines were easy to understand and use, passengers would be more inclined to use them. They felt more satisfied with the process (Lu *et al.*, 2024). Similarly, Kim et al. (2023) observed that, in a sample of Korean airport users, both the performance benefits and the ease of use of self-service systems enhanced travellers' technology acceptance and their perceived value of the service. In the context of biometric e-gates for border control, studies in the U.S. and Korea have reported that PE and EE are salient drivers of willingness to use these systems. Travellers tend to show stronger intentions to use biometric gates when they believe these systems will speed up border processing (high PE) and when they find them simple to operate (high EE(Kim, Costello and Lee, 2019).

Beyond intention, earlier studies show that these perceptions also shape users' satisfaction after using a technology. In airport settings, passengers generally report greater satisfaction when a self-service system genuinely reduces waiting time or when the interface feels uncomplicated (Wongyai *et al.*, 2024). Similar patterns have been observed in digital travel services. Yuan, Tseng, and Ho (2019) found that perceived usefulness had a direct and positive influence on passenger satisfaction with airline mobile apps(Yuan, Tseng, and Ho, 2019). Of note, a recent study from Europe supports this point, demonstrating that the usefulness and ease of use of automated services, such as passport control and self-check-in, were reliable predictors of overall satisfaction scores (Simarmata *et al.*, 2025). These results align with much Research in information systems, which identifies perceived system quality (ease of use) and usefulness as key factors in passenger satisfaction. (Ursava, 2022). It is also important to note that the strength of these relationships could differ from passenger to passenger. For example, passengers with limited prior experience are often more sensitive to the effort required to use a system. In contrast, experienced users tend to view ease of use as less critical (Ursava, 2022). In summary, PE and EE are fundamental to understanding technology uptake and satisfaction in airports. High perceived usefulness (e.g., "using this self-service kiosk will make my trip more efficient") and high perceived ease (e.g., "it is easy to operate this kiosk") generally foster positive attitudes, usage intentions, and satisfaction. Nevertheless, these perceptions do not exist in a vacuum – they are experienced by individuals who bring their own cultural backgrounds and adaptive capabilities to the situation. A passenger who finds a helpful kiosk and, in theory, easy to use might still not be satisfied or fully utilise it if, for example, they could struggle with language differences or unfamiliar procedures. This points to the importance of PCCA, which we explore next.

2.3 Cross-Cultural Adaptation and Technology Use in Travel

Cross-cultural adaptation is defined as the procedures by which individuals adjust to an unfamiliar cultural environment, acquiring the skills and comfort necessary to function effectively (Ahmed *et al.*, 2022). Key aspects of adaptation involve learning local norms/language, coping with "culture shock," and modifying behavior as a result (Leal *et al.*, 2017). In the context of tourism and travel, visitors, even for short stays, often have to deal with these challenges in simple ways—such as understanding signs written in a foreign language or using technologies designed for a local user base (Dube and Humbani, 2024).

Travelers differ in their propensity to adapt to new cultural environments: some possess high cultural intelligence and readily accept new cultures (Ang et al., 2007), while others experience difficulties and stress when confronted with new cultures (Wardle, 2003). This variability can significantly impact travel experiences. For instance, Cultural Intelligence (CQ) – a related construct defined as the ability to function effectively in culturally diverse situations – has been linked to better satisfaction with travel services. (Coves-Martínez, Sabiote-Ortiz and Frías-Jamilena, 2022) Demonstrated that tourists with higher CQ reported greater satisfaction with a mobile travel app and with their overall trip, presumably because they could overcome language or format barriers in the app and derive more value from it. This refers to individuals who are adept at cultural adaptation, being able to more fully utilise and appreciate technological services encountered abroad, leading to higher satisfaction. In an airport setting, PCCA might manifest as passengers struggling with technology interfaces that are not tailored to their home culture. Airports strive to be international, yet the implementation of technology inevitably carries local specificities (e.g., a kiosk might default to the local language or assume knowledge of specific airport processes) (Lim, Innes, and Meitner, 2015). A traveller's PCCA can determine whether these differences are experienced as minor inconveniences or major hurdles.

A traveller with a high level of PCCA is generally more comfortable navigating unfamiliar elements in the airport environment. They can adjust language settings on a kiosk, interpret symbols that differ from those at home, and confidently seek assistance when needed. These behaviours reduce stress and make it easier for them to use self-service technologies effectively.

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In contrast, a traveller with low PCCA may find that even small differences—such as an unfamiliar credit card swipe direction or slightly different identification procedures—can create confusion and slow them down. These minor mismatches can quickly accumulate into frustration, limiting both their use of the technology and their overall satisfaction. Notably, ACI's global survey reported that certain cultural groups rate courtesy and human warmth highly in their satisfaction evaluations; these passengers might be less satisfied in a heavily automated airport if their expectations for human help or social interaction are unmet. Thus, airports face the challenge of finding the optimal balance between technological efficiency and human touch (Lee, 2024), especially given the cultural diversity of international travellers. Cultural differences in service expectations are well documented. For example, Eastern cultures may place more emphasis on hospitality and human support. In contrast, Western cultures might prioritise speed and autonomy (Wattanacharoensil, 2019).

Accordingly, smart airport initiatives must consider cross-cultural user needs to ensure that improvements in one dimension (such as efficiency) do not inadvertently erode satisfaction for some groups (ACI, 2024). In conclusion, smart airports seem to be a meeting point for technological innovation with sustainability goals. These airports could seek to enhance passenger satisfaction by providing faster, more reliable, and environmentally friendly services (Eshtaiwi *et al.*, 2018). The success of these technologies in airports depends on passenger acceptance, which is influenced by factors such as perceived performance benefits, the effort required, and cross-cultural adoption. In summary, the authors propose that PCCA acts as a crucial link between travellers' perceptions of smart airport technology and their eventual satisfaction. If a passenger has high performance and EE regarding a new self-service system, a high PCCA will enable them to capitalise on those positive perceptions by overcoming any cultural or contextual hurdles during use, resulting in a satisfying experience. On the other hand, if PCCA is low, even strong initial PE/EE may falter in practice; the traveller might not fully utilise the technology or use it under stress, dampening satisfaction. This mediating role of PCCA in technology acceptance and satisfaction has not been extensively studied, making it a focal point of our Research.

2.4 Passenger Satisfaction in Multicultural Service Environments

Passenger Satisfaction in the airport context refers to travellers' contentment with their airport experience and services. High satisfaction is associated with positive word of mouth, loyalty, and a greater likelihood of choosing the same airport or airline again (Han *et al.*, 2020). Satisfaction is typically conceptualised as resulting from the disconfirmation of expectations (Ali *et al.*, 2021) – passengers compare their pre-travel expectations of airport service quality with the actual performance they perceive. Smart technologies have introduced new dimensions to this evaluation. Modern passengers might expect quick, convenient, and digitally enabled services; meeting these expectations through technology can drive satisfaction, while any gap (e.g., technology breakdowns, confusing interfaces) can lead to dissatisfaction (Sharma, 2024). Prior Research has identified various determinants of airport passenger satisfaction, such as service efficiency, staff courtesy, facility cleanliness, security processing, and amenities (Halpern and Mwesiumo, 2021). With the proliferation of SSTs, "technology service quality" has become a pertinent factor. (Khan *et al.*, 2024) Note that reliability, responsiveness, and usability of self-service technologies contribute to perceptions of e-service quality. At airports, if kiosks or e-gates function reliably and swiftly, passengers view the service as high quality, boosting their overall satisfaction (Kim, Stepchenkova, and Babalou, 2018).

In contrast, satisfaction is likely to decrease if a machine malfunctions or if it is difficult to operate, even if other factors, such as staff courtesy, are exceptional. Therefore, it is now essential to manage airport satisfaction by guaranteeing a seamless digital service experience (Greer, Rakas, and Horvath, 2020). In multicultural passenger bases, perceptions of satisfaction can vary by cultural background. As discussed, ACI (2018) found that cultural differences influence what passengers value; for example, passengers from collectivist cultures might place greater weight on how family-friendly and accommodating the airport is. In contrast, those from individualist cultures focus on personal convenience and efficiency. The disparities indicate that a uniform strategy for enhancing satisfaction may be inadequate in an international airport; the design and execution of services, including technology, must be attuned to varied requirements. These measures can improve comfort and satisfaction for diverse groups (Wang *et al.*, 2024). Nonetheless, personal adaptability (PCCA) is expected to affect satisfaction in an environment where complete customization to each culture is unattainable. Satisfaction arises from a complex interaction between service performance and user variables. Our Research focuses on how user perceptions of technology (PE, EE) and their PCCA collectively influence satisfaction outcomes. Hypothesis Development (next section) will formally articulate the expected relationships between these constructions based on the above literature synthesis.

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3. Hypothesis Development

Drawing on the literature, the researcher develops five hypotheses linking PE, EE, PCCA, and passenger satisfaction (Figure 1 conceptually summarises these relationships).

H1. Performance expectancy positively affects passenger satisfaction.

This hypothesis asserts that when passengers recognize that smart airport technology offers significant advantages (high PE), they are more inclined to experience greater satisfaction with their travel experience (Rashid and Pandit, 2018). Satisfaction occurs when passengers perceive that their expectations for efficiency and convenience have been met (Venkatesh *et al.*, 2003). Suppose a traveler perceives that utilizing a biometric boarding gate will markedly decrease boarding time and alleviate stress. In that case, this perceived performance enhancement directly correlates with satisfaction with the service (Mazloum, 2025). According to (Eccles and Wigfield, 2002), individuals generally assess experiences more favorably when they attain desired outcomes (Eccles and Wigfield, 2002).

Recent studies substantiate this rationale. (Simarmata *et al.*, 2025) discovered that the perceived utility of self-service technologies in airports directly augmented passenger satisfaction by enhancing service efficiency and dependability. Likewise, (Harding, 2019) found that passengers anticipating robust performance from digital wayfinding systems demonstrated heightened satisfaction with their navigation and overall airport experience. Recently, Moon *et al.* (2025) revealed that international tourists who regarded mobile travel applications as highly beneficial exhibited greater engagement and satisfaction with their journeys (Moon *et al.*, 2025). These studies indicate that perceptions of technological efficacy considerably influence satisfaction. In the realm of smart airports, passengers with elevated perceived ease (PE) are inclined to associate technology adoption with streamlined processes, reduced waiting times, and enhanced service quality—factors that are crucial to satisfaction (Williady, Handani, and Kim, 2024). Consequently, when passengers recognize significant performance advantages, they are more inclined to assess the overall service experience favorably. Suppose passengers anticipate that smart airport technologies will provide significant efficiency and convenience. In that case, their satisfaction with the travel experience will rise.

H2: Effort Expectancy (EE) has a positive influence on Passenger Satisfaction (PS).

When passengers perceive airport technologies as simple, intuitive, and easy to operate, their overall satisfaction with the travel experience increases. A user-friendly interface—such as a clear, responsive self-check-in kiosk—reduces frustration and the cognitive effort required to complete tasks (Lu *et al.*, 2024). Passengers who can navigate these systems smoothly are more likely to feel confident and in control, which contributes to a sense of comfort and enjoyment (Hasanain, 2024). Conversely, when systems are complex or confusing, travellers often experience stress or delays before even beginning their journey, which negatively affects satisfaction (Gómez-Llanos, Durán-Barroso, and Robina-Ramírez, 2020). The "confidence factor" in service adaptation (Dash and Paul, 2021) supports this idea: people who feel capable of using a system tend to evaluate the service more positively. High EE fosters this confidence by assuring users that the technology will not be demanding or intimidating (Otieno, 2010).

Empirical studies in information systems have also shown that low perceived effort encourages users to engage more fully with a technology and to resolve issues on their own (Jan, Alshare, and Lane, 2024). In an airport context, this translates into smoother check-in experiences, shorter waiting times, and greater trust in the overall service process—all of which enhance Passenger Satisfaction. Thus, when travellers find airport technologies easy to use, their satisfaction with the journey is likely to rise.

H3: Propensity to Cross-Cultural Adaptation positively affects Passenger Satisfaction.

We expect that travellers who are more adept at PCCA (higher PCCA) will experience greater satisfaction with their airport journey (Coves-Martínez, Sabiote-Ortiz, and Frías-Jamilena, 2022). As discussed, individuals with high PCCA can navigate culturally novel situations more effectively, resulting in more successful and pleasant service encounters (Lu *et al.*, 2024). In the context of smart airport services, a high PCCA could make a passenger less likely to be deterred by, for example, language barriers or differing social norms for queuing at a kiosk (Simarmata *et al.*, 2025). Instead, they adjust and complete the process, leading to the intended outcome (e.g., a smooth check-in) and, in turn, satisfaction (Wongyai *et al.*, 2024). Meanwhile, a low-PCCA passenger might become frustrated or fail to fully utilise available services, resulting in delays or reliance on traditional counters – outcomes likely to diminish satisfaction. Findings in tourism behavior

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research support this hypothesis: for example, Coves-Martínez, Sabiote-Ortiz, and Frías-Jamilena (2022) found that tourists with higher cultural intelligence (which overlaps with adaptive propensity) experienced greater satisfaction with travel apps and their overall trip (Won, Chiu, and Byun, 2023). Those authors argue that culturally competent tourists can better handle foreign technology and content, thereby enabling the service to meet their needs better, driving higher satisfaction. Similarly, in expatriate consumer studies, individuals who adapt to the host culture tend to report higher satisfaction with local services and life in general (Lo and Nguyen, 2023). Applying this pattern to short-term airport users, we predict that PCCA will enhance satisfaction by enabling passengers to reap the benefits of smart services without being hindered by cultural frictions. Thus, a one-unit increase in a traveller's adaptation propensity should result in a significant increase in their satisfaction with airport services (Wang *et al.*, 2024).

H4: PCCA mediates the positive relationship between Performance Expectancy and Passenger Satisfaction.

This hypothesis suggests that PE influences satisfaction primarily by affecting PCCA. In other words, we expect the indirect path from PE to PCCA to Satisfaction to be significant. While PE may also have a direct effect on satisfaction (a valuable service tends to satisfy customers), we posit that in a multicultural environment, the satisfaction arising from perceived usefulness is channeled through the traveller's adaptive response. High PE motivates adaptation (as per H1), and then through adaptation, the passenger effectively uses the service and becomes satisfied (H3). Without adaptation, the benefits of high PE might not fully materialize in experience, thereby tempering satisfaction (Simarmata *et al.*, 2025). We anticipate that after accounting for PCCA, the direct effect of PE on satisfaction will diminish or become non-significant, indicating that PCCA carries the influence of PE. Empirically, Lu *et al.* (2024) observed a similar phenomenon, finding that cultural adjustment mediated the relationship between satisfaction. Here, even if passengers believe the tech is useful, it is their cross-cultural adaptability in using it that ultimately determines how satisfied they are. Thus, we hypothesize a mediated relationship: PE leads to higher PCCA, which in turn leads to higher satisfaction (PCCA mediates PE's effect).

H5: PCCA mediates the positive relationship between Effort Expectancy and Passenger Satisfaction.

Analogous to H4, we propose that EE impacts satisfaction primarily via PCCA. A high perceived ease of use will increase one's adaptation propensity (H2); with greater adaptation, the passenger uses the technology successfully and is satisfied (H3).

If adaptation is not present, even an easy-to-use system might not yield satisfaction for culturally unadaptable individuals (Lu *et al.*, 2024)—they might technically find it easy, but still avoid it or feel uneasy due to cultural disconnects, thereby not significantly improving their satisfaction. As an example, consider a passenger who finds the idea of a biometric gate straightforward (high EE) but has low adaptation propensity (Lo and Nguyen, 2023) – they may still avoid the gate due to discomfort with the concept in a foreign setting, choosing manual processing and thus not benefiting (and not particularly satisfied). Only when that passenger decides to adapt (perhaps because the ease encourages them enough to try) do they use the gate and appreciate its speed, resulting in satisfaction. In line with this reasoning, we expect an indirect effect such that EE → PCCA → Satisfaction is significant, potentially rendering any direct EE → Satisfaction effect weaker. Prior Research on IS user satisfaction often finds that perceived ease of use influences satisfaction through actual use or reduced stress (Amin, Rezaei, and Abolghasemi, 2014). In our model, PCCA can be viewed as an enabler of usage under cultural variance, fulfilling a similar role. Therefore, the current study hypothesizes that PCCA mediates the relationship between EE and passenger satisfaction.

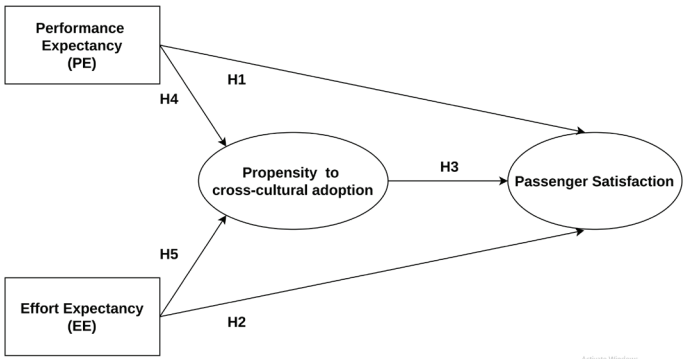

Figure 1: conceptual model of hypothesised relationships

4. Methodology

4.1 Research Design and Context

This Research employs a quantitative research design using a single cross-sectional questionnaire to collect data from air travellers. The research setting is Alexandria International Airport, which is the second-busiest airport in Egypt and a regional hub for several

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airlines. The study selects this airport because it serves a highly diverse mix of passengers—North African, Gulf, European, and Asian—and because it has been actively rolling out smart technologies, including newly installed self-check-in kiosks and pilot-phase biometric immigration gates (ElMassah, 2018; Helmy, 2018). Moreover, focusing on a single airport may minimize variations in service quality across different locations while still capturing a wide range of cultural reactions to the same technological setting. The study was conducted over six months, from November to April 2025, during the return of high travel volumes following the pandemic. Throughout this time, health-related restrictions were minimal, and the airport operated close to full capacity. This created a realistic and dynamic environment in which to observe how travellers interacted with smart technologies and how these interactions shaped their satisfaction.

4.2 Sample and Data Collection

The target population was international departing passengers who had the opportunity to use the airport's self-service technologies, particularly the touchless biometric self-service check-in kiosks (referred to as TBSS in the survey). The study used a random sampling method in the airport's departure hall. The questionnaire was offered in English and Arabic, covering the dominant languages of the airport's users. To encourage honest feedback, respondents were assured of anonymity and that the survey was for academic purposes, with no influence on their travel or airline. The survey took approximately 7–10 minutes to complete, which was feasible during waiting times. A total of 1,200 passengers were approached. Of these, 1,050 agreed to participate (response rate: 87.5%). After discarding incomplete questionnaires (e.g., those missing entire sections) and those with apparent straight-line answering, we retained 1,025 valid responses for analysis. This sample size exceeds the minimum requirements for SEM given our model complexity (Hair et al., 2010) and allows robust hypothesis testing, including mediation, via bootstrapping. The sample encompassed a broad demographic range.

Approximately 56% of respondents were male and 44% female. Ages ranged from 18 to 72, with a median age in the early 30s. The largest age group was the 20s (roughly 34% of the sample), followed by the 30s (27%), the 40s (18%), and the 50s (13%), with smaller proportions in the teens and 60+ categories (as shown in Table 1). Education levels were relatively high: about 60% held a bachelor's degree or higher, 25% had some college or technical diploma, and 15% had secondary or lower education. The participants in this study were almost equally divided between men (498; 48.6%) and women (527; 51.4%), showing a balanced gender distribution. In terms of age, most respondents were in their forties (26.1%) and twenties (24.8%), followed by those in their fifties (17.7%) and thirties (16.3%). The youngest group (10–19 years) represented about 15% of the sample, while older adults were less frequently represented. Educational levels varied considerably. A quarter of participants reported having a graduate degree (25.5%). In comparison, others held a university degree (19.5%), a college diploma (21.5%), or a high school qualification (19.1%). Interestingly, 23.8% reported "other" educational backgrounds, suggesting diverse academic and training pathways. Overall, the demographic profile reflects a diverse group, with balanced gender representation, broad age coverage, and relatively high educational attainment. This variety provides a strong basis for interpreting the study results across different subgroups. Importantly, all respondents had used the TBSS kiosk for check-in or boarding pass printing for their current flight, as intended; their prior exposure to such technology ranged from first-time users (about 20% indicated it was their first experience with airport self-check-in) to regular users (around 30% had used such kiosks more than 7 times in the past). This variation helps capture differences in PE, EE, and adaptation.

Table 1: illustrates the demographic variables

Demographic variables	Criteria	Frequency	Percentages
gender	Male	498	49.8%
	Female	527	50.2%
age	10s (10–19)	153	%14
	20s (20–29)	255	%25
	30s (30–39)	267	%26
	40s (40–49)	268	%26
	50s (50–59)	42	%4
	60s and above	40	%4
level of education	High school	196	%19
	College (2–3 years)	241	%23.5
	University (bachelor's degree)	280	%27
	Graduate school (master's or higher)	262	%25.5
	Other	46	%4

4.3 Measures and Instrument Development

The Research evaluated four latent constructions using 5-point Likert-type items (1 = Strongly Disagree, 5 = Strongly Agree), each modified from recognized models specifically relevant to airport self-service. We used four UTAUT items (Venkatesh *et al.*, 2003) to measure PE. These items ask how much the kiosk improves travel efficiency, productivity, and the overall

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experience (for example, "Using the self-check-in technology improves my travel efficiency"). Four UTAUT items were used to assess EE. These items focused on how easy it was to learn how to use the system, how well it worked, and how much mental effort it took (e.g., "It was easy for me to learn how to operate the self-check-in kiosk"). The PCCA consists of four items, derived from the literature on cultural intelligence and adaptation (Ang *et al.*, 2007), to evaluate openness and ease of adjustment to unfamiliar technologies and cultural environments during travel (e.g., "I can adapt easily to technologies used in other cultures"). In the end, Passenger Satisfaction (PS) was measured using four items from service satisfaction studies (Brady and Robertson, 2001) that assessed both cognitive and emotional evaluations of the self-service experience (e.g., "Overall, I am satisfied with the self-check-in service"). These measures, together, assess how passengers feel about airport technology in terms of its usefulness, ease of use, cultural adaptability, and overall satisfaction.

All scale items were arranged by construct in the questionnaire, with clear section headings (e.g., "Please indicate your agreement with the following statements about the self-check-in technology…"). The use of a 5-point Likert scale throughout made it easy for respondents and is a common choice in travel surveys, where extreme granular scales may not yield proportionally more information. The survey instrument was developed in English and then translated into Arabic using a back-translation method to maintain semantic equivalence (Barakat *et al.*, 2023).

5. Data Analysis Approach

Pre-Testing: Before field deployment, the survey was pilot tested with 156 individuals (including graduate students and airport passengers) to assess clarity, translation accuracy, and relevance. Feedback led to minor wording adjustments, especially on the PCCA items to ensure they were interpreted as intended (for example, clarifying "technologies used in other cultures" by giving a concrete hint like "(e.g., different countries' airport systems)" in the pilot, which was later streamlined). The pilot also checked the flow and approximate completion time. Based on pilot data, the scales demonstrated promising internal consistency, and respondents found the questions comprehensible (as shown in Table 2). The results indicated that all factor loadings met the 0.50 threshold (Simarmata *et al.*, 2025), ranging from 0.701 to 0.962, confirming acceptable indicator reliability. In addition, the composite reliability (CR) values reached the optimal level of 0.70 (Elshaer *et al.*, 2021), with scores ranging from 0.807 to 0.855 across the four constructs. The average variance extracted (AVE) values also exceeded the required 0.50 threshold (Wongyai *et al.*, 2024), ranging from 0.512 to 0.596, thereby supporting convergent validity. Model-fit indices indicated that the measurement model's overall structure was appropriate: Chi-square = 384.972, degrees of freedom (df) = 192, GFI = 0.904, AGFI = 0.861, IFI = 0.963, TLI = 0.951, and CFI = 0.962 (Mueller and Hancock, 2018). Although some researchers argue that model-fit indices alone do not fully determine model adequacy, additional indices, such as $\chi^2/df = 2.01$ and RMSEA = 0.047, further confirm that the model achieved an acceptable and reliable fit to the data.

Table 2: Scale Items and Confirmatory Factor Loadings (pilot study)

Construct	Items	Factor Loadings	Composite Reliability (CR)	AVE (%)
Performance Expectancy (PE)				
(Venkatesh *et al.*, 2003)	PE1	0.802	0.841	57.3
	PE2	0.818		
	PE3	0.794		
	PE4	0.831		
Effort Expectancy (EE)				
(Venkatesh *et al.*, 2003)	EE1	0.765	0.855	59.6
	EE2	0.786		
	EE3	0.781		
	EE4	0.770		
Propensity to Cross-Cultural Adaptation (PCCA)				
(Li, 2024)	PCCA1	0.701	0.807	51.2
	PCCA2	0.744		
	PCCA3	0.962		
	PCCA4	0.715		
Passenger Satisfaction (PS)				
(Fodness & Murray, 2007)	PS1	0.734	0.843	57.3
	PS2	0.788		
	PS3	0.761		
	PS4	0.757		

5.1 Measurement Model Assessment

The confirmatory factor analysis on the four latent constructs (PE, EE, PCCA, Satisfaction) demonstrated a good fit to the data. Reliability and validity checks confirmed the adequacy of the measurement model before hypothesis testing. Following Hair, Howard, and Nitzl (2020), all items met the accepted cut-off values for factor loading (≥ 0.50), composite reliability

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(≥ 0.70), and AVE (≥ 0.50) (Hair, Howard, and Nitzl, 2020). Discriminant validity was also established, as the square root of each construct's AVE exceeded its inter-construct correlations (Fornell and Larcker, 1981; Alarcón et al., 2015). The CFA results supported the model's overall fitness (χ^2/df = 1.998; CFI = 0.986; NFI = 0.973; IFI = 0.986; TLI = 0.983; RMSEA = 0.032). These indices, together with high reliability coefficients and satisfactory AVE values, indicate that the measurement model is both reliable and valid. Consequently, it provides a strong empirical basis for proceeding with hypothesis testing (Ali *et al.*, 2019).

5.2 Non-response bias and common method bias

Non-response bias is a type of bias that researchers test for; it is not a technique that guarantees the absence of disparity between initial and subsequent replies (Ali *et al.*, 2019). Levene's test showed a non-significant p-value, suggesting no difference between early and late replies. Standard method bias will be assessed to confirm that no single item accounts for 50% or more of the overall variation (K and Ranjit, 2020). The results of the bias (Zhang and Merchant, 2020).

Table 3: Scale Items and Confirmatory Factor Loadings (main study)

Construct	Items	Factor Loadings (λ)	Composite Reliability (CR)	AVE
Performance Expectancy (PE)	PE1	0.764	**0.862**	**0.611**
	PE2	0.755		
	PE3	0.78		
	PE4	0.826		
Effort Expectancy (EE)	EE1	0.805	**0.871**	**0.628**
	EE2	0.785		
	EE3	0.793		
	EE4	0.787		
Propensity to Cross-Cultural Adaptation (PCCA)	PCCA1	0.696	**0.808**	**0.513**
	PCCA2	0.69		
	PCCA3	0.729		
	PCCA4	0.749		
Passenger Satisfaction (PS)	PS1	0.767	**0.858**	**0.603**
	PS2	0.775		
	PS3	0.766		
	PS4	0.799		

Note: *For PCCA3, λ = 0.962 implies $R^2 \approx 0.925$; the original AMOS output showed 0.479, which appears to be a typographical error.

5.3 Discriminant validity

Discriminant validity was confirmed by comparing the square root of the AVE for each construct with its correlations (Eid, Ali, and Barakat, 2024). As shown in Table 3, all √AVE values (PE = 0.782, EE = 0.793, PCCA = 0.716, PS = 0.777) exceeded the inter-construct correlations, indicating satisfactory discriminant validity. Composite Reliability (CR) values were also above the 0.70 threshold, confirming internal consistency: CR = 0.841 (PE), 0.855 (EE), 0.807 (PCCA), and 0.843 (PS). These results collectively demonstrate that the measurement model possesses strong reliability and both convergent and discriminant validity.

Table 4: Convergent Validity (AVE and √AVE)

	PE	EE	PCCA	PS	SQR AVE
PE	1.000	0.132	0.293	0.084	0.781728374
EE	0.132	1.000	0.002	0.211	0.792538327
PCCA	0.293	0.002	1.000	0.079	0.716407356
PS	0.084	0.211	0.079	1.000	0.776864049

5.4 Structural Model Results

The hypotheses were examined using covariance-based structural equation modeling (CB-SEM). The results refer to the fact that PE had no significant direct effect on Passenger Satisfaction (PS) (β = 0.065, p = 0.292); therefore, H1 was not supported. In contrast, EE positively influenced Passenger Satisfaction (β = 0.203, p = 0.000), supporting H2. The third hypothesis (H3) was validated, as PCCA demonstrated a significant direct effect on Passenger Satisfaction (β = 0.164, p = 0.009). In addition, PCCA represents a mediating role in two relationships: it mediated the relationship between PE and PS (β = 0.082, p = 0.008), supporting H4, and also mediated the link between EE and PS (β = 0.015, p = 0.006), confirming H5. These findings collectively highlight the essential influence of passengers' cross-cultural adaptability on their satisfaction with airport self-service technologies. Figure 2 presents the structural model with standardized path coefficients and significance levels for clarity.

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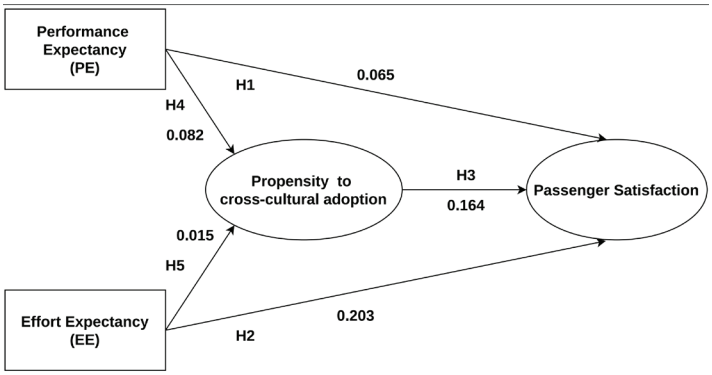

Figure 2: main study results

6. Discussion

The integration of smart applications has significantly transformed airport operations, making it essential to identify strategies that support their smooth adoption. This Research examines the impact of specific elements of the UTAUT framework on the use and passenger experience with smart airport technologies. Specifically, the study focuses on how performance expectations, perceived effort expected, and cross-cultural adaptability impact passenger satisfaction with smart airport services. The study employed CB-SEM for our data analysis. The results provided strong support for the model by illustrating how travelers use self-service technologies at Alexandria Airport. The initial hypothesis (H1) examined whether expecting optimal system performance would lead to increased satisfaction. Although previous research (Davis, 1989; Venkatesh *et al.*, 2003) suggested that perceived utility often plays a significant role, our results did not show a conclusive relationship (β = 0.065, p = 0.292). This indicates that a system seen as efficient by passengers does not inherently lead to heightened pleasure. Recent studies have elucidated this transition.

Passengers confirmed that the comfort of the experience, the system's ease of use, and the process's transparency, rather than focusing only on the expected performance (Celemín-Pedroche, Ostomo, and Escat-Cort, 2023; Sharma, 2024). As self-service options become widespread, their practical benefits are often taken for granted (Choi *et al.*, 2024), and cultural differences may further shape how useful these technologies are deemed (Jan, Alshare, and Lane, 2024). As a result, airport administrators should balance technical innovation with user-centric design and culturally aware communication to convert perceived efficiency into genuine satisfaction (Harding, 2019). The second hypothesis (H2) evaluated the impact of EE. Our analysis demonstrated a clear positive relationship between the perceived simplicity of a system and passenger satisfaction (β = 0.203, p = 0.000). This aligns with findings indicating that intuitive and user-friendly interfaces reduce cognitive burden and bolster user experience (Venkatesh *et al.*, 2003; Amin, Rezaei, and Abolghasemi, 2014). When travellers use airport technologies without feeling weighed down, they usually end up more relaxed and more in control of what is happening around them.

That calmer state tends to make the whole airport experience feel more comfortable (Dube and Humbani, 2024). These findings support theories of cross-cultural usability, which contend that straightforward systems help people from diverse backgrounds adjust more readily (Ang *et al.*, 2007). Enhancing instructions, providing clear signage, and ensuring quick support can all contribute to higher satisfaction. For the third hypothesis (H3), the study result showed that individuals with higher levels of cultural adaptability reported greater satisfaction with self-service options (β = 0.164, p = 0.009). This adaptability seems to ease uncertainty and build confidence when travellers face unfamiliar procedures (Ang *et al.*, 2007; Lu *et al.*, 2024). Our findings further support the idea that cultural intelligence plays a central role in shaping how services are evaluated in multicultural settings. In practical terms, airports can respond to this by introducing clearer multilingual signage, using universally recognisable symbols, and training frontline staff in cultural awareness and communication. We also examined whether intercultural adaptability mediates the relationship between expectations and satisfaction.

Hypothesis four (H4) proposed that adaptability acts as the mechanism linking performance expectations to eventual satisfaction (β = 0.082, p = 0.008). Although high performance expectations did not directly predict satisfaction, they did influence it indirectly by encouraging adaptive responses. This suggests that when airports clearly communicate the benefits and advantages of smart systems, they prompt passengers to adjust their behaviour—ultimately leading to a more positive experience (Eccles and Wigfield, 2002; Ang *et al.*, 2007). Hypothesis five (H5) confirmed that adaptability also mediates the relationship between ease of use and satisfaction (β = 0.015, p = 0.006). Thus, when passengers find self-service solutions user-friendly, they feel better equipped to navigate unfamiliar cultural or procedural scenarios (Lu *et al.*, 2024). Improve satisfaction not only directly but also by supporting adaptive actions, leading to a smoother and less stressful airport journey (Davis, 1989; Venkatesh *et al.*, 2003). To conclude, our Research highlights that while high performance expectations alone are insufficient for increasing satisfaction, ease of use, and adaptability across cultures are vital. Passenger perceptions of self-service technologies are primarily influenced by their accessibility, reliability, and inclusiveness. For airport

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authorities, this underscores the importance of not only technical quality but also of fostering an environment that encourages trust, comprehension, and cultural inclusivity for all passengers.

7. Conclusion

Airports are becoming more automated each year, but technology alone does not shape the passenger experience. The people who use these systems—coming from different cultures, languages, and levels of familiarity with digital tools—remain central to how well airport services work. Insights from Alexandria Airport illustrate this clearly. Even when modern self-service options are available, satisfaction does not automatically improve. What truly matters is whether travellers can adapt to technology and feel comfortable using it in an environment that may differ from what they are used to at home. In other words, smart airports succeed only when passengers can adapt, not when new machines are installed. PE and EE both play a central role in encouraging passengers to adapt to new smart services, and this adaptive behaviour ultimately feeds into their overall satisfaction. Importantly, the findings show that PCCA acts as a bridge, mediating the effects of perceived usefulness and ease of use on satisfaction. In other words, the advantages of smart technologies are only fully realised when travellers are willing—and able—to adapt to them.

Theoretical contribution: These findings integrate perspectives from technology acceptance and cross-cultural consumer research, suggesting that models of technology use in travel contexts should incorporate concepts of cultural adaptation to better explain the results. The study's findings indicate that PCCA represents a turning point in how travelers understand smart airport services. It also helps explain why two people might interact with the same system but leave with vastly different impressions, one satisfied and the other frustrated. Moreover, the study strengthens existing knowledge on smart tourism and helps clarify why user experiences diverge so sharply.

Practical contribution: The effects are clear and profound; investing in the human element is as much about investing in technology itself. By creating systems that focus on users and adapt to different cultures, helping passengers adjust to changes, and providing other choices for those who need them, airports can ensure that new technology leads to happier customers. By doing so, smart airports can become not just technologically advanced but also truly inclusive and sustainable, delivering superior experiences to travelers from all walks of life.

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The Interplay of Pricing, Quality Perception, and Global Logistics in Ultra-Fast Fashion: A Google Trends Analysis of Shein's Worldwide Consumer Interest

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Abstract

Purpose: *The research aims at revolutionizing the global apparel industry, probably one of the greatest side effects of ultra-short fashion retailers (just think of a label like Shein). While part of their great success can be attributed primarily to aggressive pricing and wise production methods, another aspect that has been so far underinvestigated seems related to it: the role international logistics plays in consumer perception. The aim of this study is to explain the complex interaction between consumer search interest in Shein's core product attributes, price, and quality, and their shipping and customs infrastructure. As such, the primary objective is to describe the process by which consumers search for information that relates to determining how much logistical components are affected by or exist as a component of basic assessments of products.*

Methodology: *The research involves a one-year data set (August 2023 to August 2024) of global search interest shown through Google Trends, by using the quantitative and longitudinal methods. A multi-method analytical framework was implemented, incorporating: 1) A time-series analysis to capture trends over time; 2) Pearson correlation to identify the strength of linear relationships; and 3) Cross-correlation to assess tentative dynamic inter-temporal relationships between consumer queries. The previous approach was executed against three search queries: specifically using "Shein quality", "Shein prices", and "Shein shipping and customs duty," related to this context, thereby allowing for modeling the linear and synchronicity of consumer interest.*

Findings: *Results reveal a strong positive correlation (r = 0.94) between search interest in "Shein prices" and "Shein quality," indicating that consumers evaluate these two dimensions concurrently. Time-series analysis further identifies a behavioral sequence in which price interest emerges slightly ahead of, or simultaneously with, logistical Interest, suggesting that price functions as the primary trigger for broader consumer engagement. Quality-related searches exhibit a co-occurrent association with "Shein shipping and customs duty," implying that consumers assess product condition, delivery reliability, and returns accessibility as part of an integrated quality evaluation.*
Research implications and limitations: This paper adds to the literature on consumer behavior, specifically addressing pathways of information-seeking in e-commerce, by empirically delineating information-seeking relevant to product-centric versus logistical queries. The results confirm a well-rounded schema of perceived value and risk where logistical elements may be peripheral but are still nonetheless deemed critical secondary evaluative criteria. A limitation of this study is the use of search data that were aggregated and contextualized, which inhibits causal inference and demographic segregation. Additionally, the 12-month observation window may constrain the generalizability of temporal patterns identified.

Practical implications and limitations: *Results from the study indicate that practitioners in the ultra-fast fashion sector should adopt an integrated marketing strategy that reinforces their price value proposition with clear quality assurances. Critically, when price-driven promotions are activated, these should be actively supported*

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by transparent communication regarding delivery timelines and customs procedures, as this proactively shapes consumer expectations and sustains engagement beyond the initial price attraction. Addressing quality perception, on the other hand, requires that returns' policies be not only clearly articulated but also internationally accessible and straightforward to navigate since the ease of cross-border returns is itself a logistical outcome that directly influences how product quality is perceived. Finally, as the data used in this study are sourced globally, their applicability may be limited in regional markets with distinct consumer behaviors and logistical profiles.

***Originality:** This study makes an original contribution by applying cross-correlation analysis to publicly available search data to map the consumer consideration process in an ultra-fast fashion. It provides empirical evidence that logistical factors, specifically shipping and customs, are not evaluated in isolation, but are intrinsically assessed alongside core product attributes, offering a more comprehensive understanding of how value is perceived in international direct-to-consumer retailing.*

***Keywords:** Ultra-Fast Fashion; Shein; Google Trends; Consumer Behavior; Global Logistics; Shipping; Customs; De Minimis; Price; Quality; Cross-Correlation.*

1. Introduction

The ultra-fast fashion retailers have quickly reshaped the global retail landscape. These characteristics are driven by China-based e-commerce juggernauts, such as Shein, which have disrupted traditional clothing supply chains and consumer shopping habits around the world (Degli Esposti et al, 2024; Qu, 2024). One of the reasons Shein is unique is its proven speed from design to production (highest), on-demand manufacturing, and strategies for pricing that even lead to offering an array of accessories, such as jewelry (Kilpatrick, 2022). With the incorporation of real-time data analytics and agile execution right into manufacturing produced directly at the consumer (DTC) line, it has taken away first financial shares, literally changed the paradigm in accessibility to cost-effective & fashion trends, especially with the young audience (Uchańska-Bieniusiewicz & Obłój, 2023).

Practically, Shein is supported by an intricate digital supply chain that involves large international networks that are engaged from production to retail channels. The movement of millions of parcels around the globe depends on such a big and complex plastic system: large numbers of parcels are delivered every day to clients in many different continents, and this effective international transport comes entangled with dense customs rules (FreightAmigo, 2024; Sabio, 2023; Portless, 2023). Its expenditure scheme and accelerated processing have the implementation of "de minimis" regimes as its most important feature (see e.g., U.S. Section 321, which creates duty-free treatment for packages valued below $800, so that ground shipping tariffs are avoided (Wang, 2022)). In short, Shein's competitive advantage is rooted in its ability to provide super low prices while managing a global supply chain from the factory.

However, this fast growth scheme poses other crucial concerns, such as product quality indeed manufacturing quality or around the environmental consequences (externalities) from abstract expenditure use and ethical limits in its supply chain concerning labor exploitation allegations and vague consideration of corporate social responsibility codes of practice (Degli Esposti et al. 2024; Donker & Fromke, 2023; Renz, 2022; Qu, 2024; Bowman, 2024). From the consumers' perspective, the biggest draw of Shein thus far has been value; chic items at unbeatable prices that other retailers simply cannot offer. Nevertheless, this value proposition is inextricably linked to a perpetual debate around two aspects: the gap that exists between its true quality and the market quality of their offerings, as well as the efficiency or transparency degrees of shipping and customs procedures included in their very own delivery (IIMS Pune 2023; Xiao & Qinxin 2024). Price and quality are direct features and attributes, shipping and customs are indirect but still deeply impact final cost, delivery time frame, and customer experience, thus defining the global perception of value, which in turn drives the purchasing decision.

While the existing literature has extensively examined Shein's business model and its broader economic impact, including its influence on global logistics networks and customs movements, the direct relationship between consumer interest in Shein's pricing and quality attributes and the underlying logistical infrastructure remains largely underexplored. Existing studies tend to focus on how consumers are drawn to Shein through its pricing or quality proposition, yet the simultaneous examination of these product-centric concerns alongside logistical and customs-related search behavior has received limited academic attention. In this regard, Google Trends data offer a particularly valuable lens, as it captures aggregated

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public search interest rather than individual purchasing intent, thereby reflecting broader patterns in how consumers collectively seek and process information (Boufous, 2024; Deore, 2024; Vervology, 2024).

The purpose of this research is to untangle the biggest consumer problems from global search interest. Therefore, this paper intends to investigate the estimation of global consumer search interest with respect to Shein price and quality, as well as shipping/customs associated with the brand. More specifically, we focus on:

- Global Interest trends for Shein quality, prices, and shipping and customs duty over a 12-month period
- Quantifying how related these search terms are to examine the degree of co-variation among the public Interest in them.
- Using cross-correlation for inferring behavioral sequences with respect to related product attributes and logistics concerns to determine any latent sequential relations.

In a world where global direct-to-consumer platforms seem to take precedence, the research creates awareness on consumer interactions with these aspects and is especially relevant for sectors relating to logistics and supply chain management, e-commerce strategy, and international trade policy development.

2. Literature Review

As the retail sector undergoes rapid transformation driven by the widespread adoption of digital technologies and evolving consumer behaviors, ultra-fast fashion has emerged as one of the most disruptive forces in the industry. This literature review establishes the theoretical framework for the study by examining the interrelationships among price, quality, and logistics within Shein's global ecosystem. It reviews the existing literature on ultra-fast fashion business models, cross-border e-commerce logistics, de minimis thresholds in international trade, and consumer behavior in online fashion retailing.

2.1. The Ultra-Fast Fashion Business Model

The ultra-fast fashion model, of which Shein is one of the most pronounced examples, has evolved beyond fast fashion, as it has even more increased the speed of design, production, and distribution (Barnes & Lea-Greenwood, 2010; Cheng & Li, 2023). This new model was defined by several foundational pillars. The former is the on-demand/small production strategy, which can ensure less waste and fast response to real-time trends/adaptations in the fashion scene or consumer needs, thus minimizing inventory risk (Wang & Zhang, 2021; Qu, 2024). More specifically, Shein utilizes extensive data analytics (referred to as "real-time intelligence") to identify trends before they go mainstream and apply those designs to new products almost immediately (Kilpatrick, 2022). Such rapid-fire iteration (and constant stream of new styles – sometimes in the thousands, per day) is also indicative of its operational dexterity (Degli Esposti et al., 2024).

Second, the ultra-fast model completely skips traditional retail intermediaries, instead operating through a direct-to-consumer (DTC) e-commerce channel for most of their processes. This type of vertical integration, from design to customer delivery, allows for better control over the supply chain and significant cost savings that can then be passed on to consumers in the form of ultra-low prices (Sproles & Burns, 2017; Uchańska-Bieniusiewicz & Obłój, 2023). This method of interaction lets you obtain real-time data on preferences, tastes, and purchases, creating a continuous loop for product generation and more nuanced marketing (Vertex AI Search Snippets, n.d.). The paradigm is different in that its digital structural nature enables economies of scale but worldwide access with little dependence on foreign-led market physical infrastructures and depends more heavily on strong digital marketing and social media presence in the region (Donker & Fromke, 2023).

2.2. The Second Country: Global E-commerce Logistics and Cross-border Problems

The audience providing it a warm reception can be explained when ultra-fast fashion, and more so ultra-fast fashion, very stealthily hiding behind thick walls of their single production base (with China being the greatest experiment, aka testing ground), are seen to be in an inseparable relationship with unmatched worldwide e-commerce logistics. That is, challenges related to geographical proximity and heterogeneous regulatory frameworks, as well as the consumer demand for just-in-time (Christopher, 2016; Lai et al., 2015). International freight forwarding, nearby warehouses and fulfillment centers, last-mile delivery collaboratives, and returns handling are typical critical logistics components (DMO based on the special topic sections of FreightAmigo, D 2020; Portless, D 2024). For example, companies such as Shein heavily invest in an advanced logistics network, with a more unified strategy of air and sea freight used based on the urgency of shipment to meet market needs, and millions of local courier services must be utilized for last-mile delivery only (Sabio, 2024). By putting out the low-price mode, they further ride on the total volume of parcels delivered daily, which creates connected economies of scale in terms of shipping charges (Bowman, 2024). Still, the complex

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arrangement of a worldwide network of suppliers, producers, and logistics providers generates risk points like delivery postponements as well as product spoilage in transit, not to mention higher environmental costs linked with long-haul shipping (Grant: 2020; Renz: 2022). Service quality, such as efficiency level in tracking and tracing shipments, communicating delivery estimates, and managing returns covering international shipments, is important to contemplate as it affects customer satisfaction of cross-border e-commerce (Grewal et al., 2004).

2.3. Importance of De Minimis Thresholds to Trade Across Borders

One important, but usually unnoticed, principle regarding ultra-low prices and the successful shipping of an item via Shein or such platforms is the principle of de minimis thresholds in international trade regulation. De minimis rules that exempt low-value imported goods from taxes, duties, and lengthy customs inspections improve the efficiency of imports (U.S. Customs and Border Protection, n.d.; WTO, n.d.). For example, in the United States, goods valued at $800 or less are imported duty–free when entered by one person on one day (U.S. CBP, n.d.). Similar thresholds can be found in other jurisdictions, although the applicable values differ (e.g., EU €150; UK £135) (European Commission, n.d.; GOV.UK, n.d.).

Shein's use of direct-to-consumer shipping, one-order-at-a-time, and low-cost parcels can therefore rely on these de minimis provisions liberally. In this way, entering under the allowed exemption of de minimis–a law in the United States that permits some imports to arrive duty-free if the value is below $800, while decreasing any import duties calculations for the end-user (Wang 2022) also avoids tariffs that would be assessed on larger consolidated shipments to retailers. Opponents contend that this provides an unfair competitive edge to foreign goods over their domestic counterparts and practices by guaranteeing tax-free treatment for packages imported in limited amounts, while further undermining efforts aimed at labor and environmental compliance (Bowman 2024). On the other hand, de minimis thresholds can readily be mathematically converted to cheap lower prices and, as a gala recipient to the end auctioneer, is a soft-faced, less mucky sales experience which further adds global purchasing power attractiveness (Portless 2024).

2.4. Online Fashion Demand: Price, Quality, and Delivery in What Consumers Consider

Therefore, dealing with consumer behavior in a complex fashion context of online media where the price and quality delivery expectations play key roles (Grewal et al., 2004; Kotler & Armstrong, 2020) requires an in-depth understanding of the interplay between lower-order and higher-order factors. This is clearly the most basic building block of ultra-fast fashion allure, as consumers can stock up their wardrobe with newer styles without any real financial outlay (Donker & Fromke, 2023; IIMS Pune, 2023). The allure of rock-bottom prices is offset, however, by post-purchase regrets as we face a form of product guilt. Often, customers balance between affordable prices and a few other determinant indicators, which include its wearability, non-fabrication quality, and ultimately environmental viability29 (IIMS Pune 2023; Qu 2024). It is through online reviews and social media that expectations are shaped long before a purchase (Cheema & Papatla, 2019).

The third leg we will ask for after the product and delivery expectations is also an enormously sensitive aspect of the online shopping experience. From food delivery to groceries, consumers demand not only fast, reliable, and transparent delivery services but also up-to-the-minute information about every order and notifications on any possible delays (Christopher, 2016; PwC, 2024). It appears that increasingly only a few customers are prepared to wait for weeks, if necessary, for their shipment monopolies in exchange for prices / the price tracking that is usually much lower (example: Products from international sellers), but unplanned delays / little transparency during customs delegation will always be annoying and lead to dissatisfaction overall (FreightAmigo n.d.). So, settling this is necessary; linkage of these aspects is critical, and unacceptable delivery may cause disregard for prices energized by quality and, on the contrary, a satisfactory (& reliable) delivery experience might better increase value created through a product (Xiao & Qinxin 2024). For retailers operating in global e-commerce, we outline how consumers rank and inter-relate their concerns.

However, this fast-growth model prompts additional critical inquiries into things like product quality, the environmental externalities of speed consumption (a.k.a. fast fashion), and ethical principles within its supply chain, which allegedly engage in exploitable labor alongside an ambiguous formulation of Corporate Social Responsibility practices (Hakiel et al., 2024; Donker & Fromke, 2023; Renz, 2022; Qu, 2024; Bowman, 2024). To consumers, the first allure of Shein is the obvious value, on-trend duds they can score at prices not found anywhere else. By issuing beacons, however, this value proposition is irretrievably bound to a timeless debate around two fronts: the testing quality and A-class quality of their products and spectrum gradients of shipping and customs procedures within their very transport (IIMS Pune 2023; Xiao & Qinxin 2024). Price and quality are direct factors, shipping and customs are indirect but still relevant elements in its approach that directly impact the final cost, delivery times, and overall satisfaction of customers with a direct

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impact on their perception of value in global terms, as well as their purchasing decision.

3. Methodology

More specifically, this paper adopts a quantitative perspective on their public search interest, using publicly available and objective data from Google Trends, an increasingly-used source of real-time and large-scale behavior patterns summarized by consensus across research domains of consumer behavior (Choi & Varian, 2012), fashion retail (Silva, Hassani, Madsen & Gee, 2019; Skenderi, Joppi Dennitto & Cristani. Underpinned by the justification of Google Trends as a proxy for market sentiment and consumer demand in previous research, we plausibly stand behind this approach of empirically measuring ultra-fast fashion dynamics. The employed methods aim to analyze the time series and relationships of consumer interests in price on Shein, quality on Shein, and all logistics sub-practices related to transporting goods and customs documents. Traditional datasets based on surveys or transactions are often limited by geographic, demographic, or platform aspects, whereas Google Trends provides a global scale of search behavior with full transparency. And so, it is well-suited for units of analysis that include digital-first brands such as Shein, where much of the consumer journey occurs online. For this reason, Google Trends is justified in the current research by three overall methodological arguments.

First, Google Trends is an immediate big data signal of behavior: how people are consuming information has previously established that it is a reliable data source to predict and explain consumer demand, retail dynamics, and market sentiment across domains (Choi & Varian, 2012; Goel et al., 2010; Preis et al., 2013). So far, the platform has mostly been used in fashion and retail disciplines for monitoring trend adoption patterns and anticipating product seasons/inquiries to different price-quality cues (Silva et al., 2019; Skenderi, Joppi, Denitto & Cristani, 2021). Those applications discuss associating and evaluating effects that are intended to be measured by this study's aim among consumers who perceive the core value dimensions of Shein.

Second, Google Trends is known to be useful for monitoring logistics and supply chains across nations or ambiguity that transcends national borders. Several studies have used search data to monitor public Interest in shipping disrupters, customs operations, and logistic bottlenecks (Jun et al. 2018). Their business model is driven by the international shipping logistics, customs processes they navigate, and de minimis ceilings governing what tariff-exempt goods can be imported into countries (namely the United States), making the search volume phenomenon around logistic-related queries unique in opening a window into consumer hesitations that conventional data sources would otherwise have failed to capture.

Third, it fits the objective of the study, which requires testing how inquiries among consumers evolve and connect over time. Experiments with search terms can be illustrative of how consumers move from price assessment → quality assessment → logistical feasibility as consumer search behavior is a frequent early step in travel planning and consumption, and these relationships can be measured using time-series and cross-correlation analysis. This is well aligned with Google Trends, as it provides low-lag data at high frequency and can reveal lead-lag behaviors among interconnected problems (Vosen & Frömmel, 2011; Jun & Park, 2016).

3.1. Data Source and Collection

The main data source of this research is the public web service Google Trends that exposes how popular search queries have been over time, with comparisons between different geographical and linguistic areas (Vervology, 2024; Boufous, 2024). For terms, Google Trends data are scaled from 0 to 100, with 100 representing peak popularity for a period and region (Deore, 2024), and numbers closer to zero indicating insufficient data. This type of normalization enables the comparison between relative search interest for different terms, even with absolute differences in search volumes (Vosen and Frömmel, 2011). Use of Google Trends data as proxies for both public attention and passing Interest through information-seeking inquiry (but not capturing absolute search counts; Jun & Park, 2016) could be applied to data up to October 2023.

The data based on worldwide search trends were derived from the 12 months running from August 25, 2023, to August 24, 2024 (to mirror contemporary consumer mood and hyped-up fast-fashion fads), while the dataset had been exported directly as a CSV file from Google Trends.

3.2. Search Terms and Timeframe

The study also specified three search queries as per the objectives of the survey, highlighting their relevance for Shein across operational-related and consumer-related dimensions (shown in Table 3)

- "Shein quality" (Worldwide)
- "Shein prices" (Worldwide)
- "Shein Shipping and duty" (Worldwide)

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These descriptors were chosen to capture not only direct consumer interest in product attributes, such as quality and price, but also the logistical infrastructure (shipping, customs) required to enable delivery partnerships between producers, parties responsible for trade facilitation/streaming of products from A to B per se, and the ultimate consumer. Now, regarding the second of these points, even more specifically, we need to emphasize that a generic term like "Shipping and customs duty" would be immediately associated with Shein, along with the surprising "Shein quality" and "Shein prices". The "worldwide" filter was applied, in accordance with Shein's international market coverage, and enabled a global view of consumer behavior. We initially set the dataset to a resolution of head weekly, so that we might capture some finer uptrends and shorter cycles in user interest.

3.3. Analytical Framework

This analytical framework included three overarching stages, which have been detailed as follows:

- Time-Series Analysis – First, the interest level for each keyword (over a 12-month period) has been plotted individually on a time-series plot. This made it easy to get a graphical overview of trends, highs and lows, and generally the stability or volatility in public Interest of each search term, followed by a composite time-series plot for easier direct visual comparison and concurrent trends across all three terms.

- Pearson Correlation Analysis: A Pearson correlation was calculated to assess the relationship between each of the search terms. For three items of Interest (Shein quality, Shein prices, and Transportation and Customs), this measure ranges from -1 (perfectly negatively correlated) to + 1 (perfectly positively correlated). Additional information about the co-move property of both items across the entire analysis span can be found in Benesty et al. (2009).

- Cross-Correlation Analysis: Cross-correlation analyses were conducted to explore possible lead-lag dynamics. This approach looks at the degree to which two time series are correlated over various lags, allowing us to determine if Interest (in our first search term) leads (precedes) or lags (follows) Interest in a second search term (Box & Jenkins, 1970). This is particularly important in inferring the temporal sequence of consumer concerns, for example, whether Interest in pricing or quality leads to (or lags) Interest in logistics, unlocking the consumer inquiry and decision journey. Lags of up to ±3 weeks were detected for short-term leading or lagging indicators.

3.4. Limitations of Data and Methods

Although Google Trends provides some perspective on the broader searching patterns of humans, it has its own unavoidable set of shortcomings. Before we come to the results, it should be noted that the volume of searches between terms is measured relatively and not absolutely; this requires caution when making comparisons between different cross-terms of search terms (Vosen & Frömmel, 2011). Second, Google Trends data are aggregated, anonymized (no demographic segmentation), and qualitative: reasons that cause searches to happen. Third, it chooses search terms that are hard to discriminate between. While this methodology is not the best thing (it should have been a hypothesis-based search, with Shein shipping delay, Shein custom duty, or even Shein tracking) because of the law of large numbers and little mega enticing words search interest, still, I have no problem receiving sufficient returns from Google Trends for that tag. This means that the broader term of "Shein shipping and customs duty" was used instead, with its outcomes looked at in relation to "Shein prices" and "Shein quality," providing context when viewing Shein-specific search traffic. Last but not least, correlation does not imply causation: Cross-correlation suggests lead-lag patterns among search interests, but this method alone cannot prove a clear relationship of cause and effect. The trends we experience may not be the same as in the future, and so this analysis is limited by an arbitrary suspension of time, limited to a particular dataset.

4. Results

The following section displays the results through a series of different analyses performed on Google Trends data: the statistics outline general global trends over time, whereas correlation and cross–correlation analyses show some statistical measures quantifying relationships.

4.1. Overview of Search Interest Trends

Our insights showed that, globally, Google trend analysis over the months from August 2023 to August 2024 presented specificities regarding "Shein quality," "Shein prices," and concerns regarding shipping and customs duty. It is a scale of search interest from 0 to 100, with the maximum for that term in the decade labeled as 100.

Search Interest for "Shein quality" (Figure 1): Between August 2023 and roughly March 2024, search interest for "Shein quality" was consistently low and stable, with an index value (on a scale of 0–100) mostly between 10 and 20. Search interest began climbing slowly in April

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2024, with a peak of 83 at the start of August 2024. In the weeks after this peak, search interest fell away steeply and quickly before leveling out at relatively lower levels by the end of our analysis window.

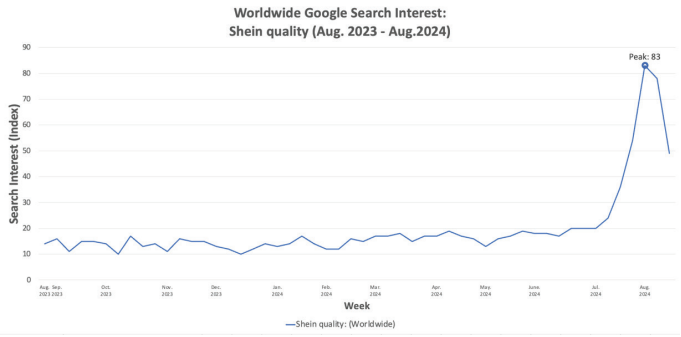

Figure 1: Worldwide Google Search Interest for "Shein quality" (August 2023 - August 2024).

Shein Prices (Fig 2): "Shein quality" started off rather slowly with values between 7-8 in the early days and spending a lot of time <10 but then climbing slowly from late 2023 onwards, and yet the associated insights on price attracted much more attention much earlier. Peaking at its all-time high index value of 100 in April 2024. After this spike, far Interest was a lot less pronounced (although not quite "Shein quality") and remained fairly constant at lower tiers until August 2024.

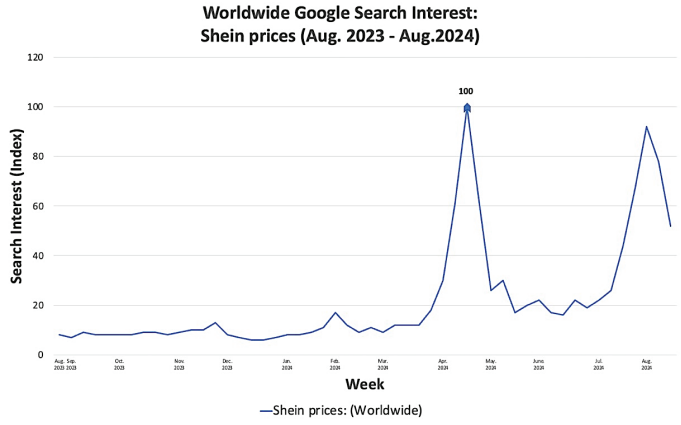

Figure 2: Worldwide Google Search Interest for "Shein prices" (August 2023 - August 2024).

Shein shipping and customs duty (Figure 3): At once, so idiosyncratic among the other two terms, both "Shein shipping and customs duty" experienced levels of search interest too low across the entire 12-month timespan to derive any valid index values, resulting instead in indexes at or around 0 through to 7 for most months, representing an entirely more rudimentary lower level of absolute public engagement. It rose at a comparatively gentle pace, peaking at 7 in early August 2024 before tapering back down again, but compared to what we witnessed for Nelson, "Shein quality" or "Shein prices", no wild spikes or peaks.

Figure 3: Worldwide Google Search Interest for "Shein shipping and customs duty" (August 2023 - August 2024).

Combined Trends (Figure 4): Figure 4 illustrates the results of the three search terms into one combined image, where it is clear to see that searches are high for Shein prices and Shein quality, versus little Interest in Shein shipping and customs duty. The vertical bands indicate when the Shein brand was having a unique moment of media attention (note that individual term data is normalized by Google Trends it may not be appropriate to sum absolute index values from differing queries) and show further these peaks being expressed in time for "Shein quality" (August 2024 - peak value time frame) and "Shein prices" (April 2024; with fellowship of prices interest along-side quality again at July-August 2024). So, the evidence that interpreting "Shein shipping and customs duty" as a sign of marginal Interest is that queries with low volume indicate indices 5–10 times lower than much higher volume brand-specific terms.

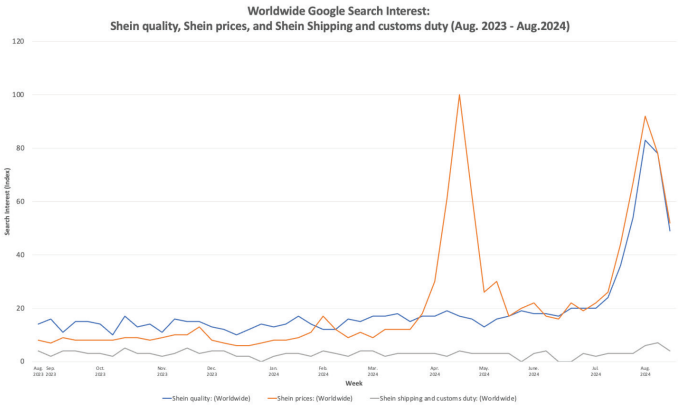

Figure 4: Worldwide Google Search Interest for "Shein quality," "Shein prices," and "Shein shipping and customs duty" (August 2023 - August 2024).

The approximately four-month gap between the peak in "Shein prices" interest (April 2024) and the peak in

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"Shein quality" interest (August 2024) warrants further consideration. One plausible explanation lies in the sequential nature of consumer information-seeking: price-related searches may represent an earlier, exploratory stage of the purchase journey, whereas quality-related searches emerge later as consumers move toward evaluation and commitment. This temporal gap may also reflect external factors active during this period, including heightened media scrutiny of Shein's product standards and labor practices in mid-2024, viral social media content questioning the brand's quality claims, or the anticipation of major promotional events, such as back-to-school campaigns in late summer. Additionally, the lagged rise in quality interest could suggest that consumers who were initially attracted by price promotions in April subsequently sought to validate their purchases through quality-related research in the following months. While the data alone cannot confirm causality, these possible explanations are consistent with established models of consumer decision-making in which price acts as an initial attractor and quality serves as a subsequent evaluative filter (Zeithaml, 1988; Grewal et al., 2004).

4.2. Behavioral Analysis: Correlation and Cross-Correlation

Pearson correlation and cross-correlation analyses were performed to gain further insight into how the search interests are related to one another.

4.2.1. Pearson Correlation Coefficients

Table 1 contains the Pearson correlation matrix, which measures how strongly and in what direction the search terms are linearly related to each other.

Table 1: Pearson Correlation Matrix of Worldwide Google Search Interest

	Shein Quality	Shein Prices	Shein shipping and customs duty
Shein Quality	1.00	0.94	0.77
Shein Prices	0.94	1.00	0.70
Shein ship. and cost. duty	0.77	0.70	1.00

The results were consistently high positive correlations between each pair of search terms, as follows:

Shein Quality and Shein Prices (r = 0.94): the extremely high positive correlation serves as supporting evidence that worldwide search interest in product quality and pricing are exhibiting similar movement due to both variables appearing simultaneously used by consumers as complementary sources of information; overall, relative to prior work flow around other brand query dynamics, they seem to take into account at a similar level of granularity.

Shein Quality and Shein shipping and customs duty (r = 0.77): the interests appear to dominate the quality of products, which has a strong positive correlation with contemporaneous but smaller magnitude spikes on shipping and customs duty searches.

Shein Prices and Shein Shipping and Customs duty (r=0.70): a high positive correlation with commercial intent was also found between Shein price searches and shipping & customs logistical score metrics, indicating that the overwhelming majority of consumers search for price information just before they search for how they can receive their goods.

Overall, the positive associations of IoU are quite well pronounced, which suggests that despite significant fluctuations in absolute search volumes, public interests in distinct operational domains of Shein go hand-in-hand and are quite likely interconnected.

4.2.2. Cross-Correlation Analysis

In order to investigate the potential lead-lag relationship between our searches, cross-correlation analysis was applied to have a better understanding of which aspect of Shein consumers are likely to turn toward in sequence.

Cross-correlation (maximum, r = 0.70) for Shein Prices vs Shein shipping and customs duty, Bi-lag at a Lag 0 suggests simultaneous movement; alternatively, at Lag +1 week, this cross-correlation could propose that Interest in Shein Prices preceded searches in Shein shipping and customs duty by one week. Such observation tells us that the behavioral pattern of increasing keyword interest related to "Shein prices" is, in fact, occurring at around the same time, or slightly preceding, consumer searches for information regarding "Shein shipping and customs duty". So, it moved from price attraction as a main button that forces the consumer to make an effort in finding out about its delivery (shipping times, costs, customs implications) during a second phase.

To find out which queries were traveling together, I computed the cross-correlation of each one with all others across lags from -15 to 15 lags. Shein Quality vs. Shein shipping and customs duty – This yielded my highest cross-correlation (r = 0.77) at Lag 0, showing that search interest in "Shein quality" mostly coincides with "Shein shipping and customs duty." Synchrony could imply that consumers assess product quality (e.g., durability, materials, reviews) together with logistical considerations, such as transport types and return

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options linked to quality characteristics attributable to transport and customs links (20).

In general, the cross-correlation results imply an interaction in consumer evaluation processes such that price interest leads logistics checks by a small margin, while choice factors per product quality and delivery impact each other concurrently, which came back to match with the integrated structure of decision making before rapidly acquiring ultra-fast fashion.

5. Discussion

This study examines the symbiotic relationship of consumer search for "Shein's prices", "Shein's quality", and related logistic questions, framed as "Shein shipping and customs duty" in an unclean sense, in addition to regarding brand logistics reference information, but as a separate term irrelevant to regulatory description search interest, controlling for that group referring to the research sample. The 12-month Google Trends analysis can provide unique insight into the way in which consumers are engaging with the ultra-fast fashion space as a whole and through a lens that is particularly relevant for an industry behemoth like Shein.

5.1. The Role of Price and Quality, Logistics in Consumer Search on Shein

In the time-series analysis (Figures 1–4), search interest in the term "Shein prices" clearly outweighs that for "Shein shipping and customs duty," with similar results being observed for "Shein quality." Broadly, this means that the consumer alert bells ring red in Shein's identification at least as far as product value proposition, or even more basic properties of a product. As evidence, "Shein shipping and customs duty" has apparent operational relevance for global DTC retailers (Christopher, 2016; Sabio, 2024), while likely a less explicit concern or more implicitly relevant issue within the general online populace. It appears to be fundamental within the buying method; however, its low related Interest in search shows that, for the average purchaser, logistics and customs in general are not being prioritized as issues or concerns unless ache points have come to a head.

The possible results (Table 1) showed an extremely high correlation of 0.94 between "Shein quality" and "Shein prices," supporting previous literature advocating for the combined view of cost and quality needed when considering consumer purchasing decision-making, especially for markets where value is among the top five considerations (Grewal et al., 2004; IIMS Pune, 2023). And so, consumers are not only price sensitive, but they also actually try to measure the resulting quality, most likely the implied value for money. Not only were search interests in both terms spiking at the same time (Figure 4), but also the stair step structure with another additional spike in July-August 2023 suggests public awareness or discourse was also increasing, and consumers were considering Shein offerings, price, and quality as a key consumption consideration. These increased mentions may be triggered by large marketing pushes, prominent media coverage, or viral social content or releases corresponding to a notable product launch/event that brings attention to the cost performance of Shein, but also attributes aspects of its product quality claims.

5.2. Some Consumer Insights: The Consumer Journey

The cross-correlation analysis provided key behavioral insights into the temporal ordering of consumer inquiry. More specifically, the fact that searches for 'Shein prices' either correlate with or even lead to a bi-weekly interest in Shein shipping and customs duty suggests coherent progression in consumers' evaluative processes. Given that the brand is characterized by its ultra-low pricing strategy (Kilpatrick, 2022), it would follow that price could immediately be recognized as an initial point of Interest for consumers. After initial attraction, consumers often quickly turn to ask logistical-related questions of importing those things - for example, how they will be shipped to her, when she might expect delivery, and potentially even customs implications (Portless 2024). This means an efficient pricing strategy is an entry ticket to any other consumer involvement, where logistical factors become more and more relevant.

In contrast, the clear parallelism at Lag 0 of "Shein quality" and "Shein shipping and customs duty" Interest means there is likely a strongly synchronous dynamic. Specifically, consumers may do this if they are doing research into Shein's quality whether by reading reviews of Shein clothes and comparing them with cheaper alternatives to discover products that might be viewed as economically superior (Donker & Fromke, 2023) or whether through media stories providing `bigger picture' perspectives such as Shein's environmental impact which lightly reframes the meaning of what quality means in the context of how global delivery comes about. Such concerns can be with regard to delivery conditions (risk of damage while in transit), feasibility and expense of returns from abroad for defective goods, or perhaps the potential dilution of quality due to long shipping durations (FreightAmigo, n.d.). Thus, this suggests that regarding quality assessment, standalone logistic factors, such as how application and product attributes are, are intrinsically bound with one another from the initial stage of the consumer's exploratory process.

At the same time, consumer worries over "quality" may have found a yet deeper conceptual level of what

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properties of durable or material features are, and about ethics and environmental dimensions like human rights, conditions of labor for manufacturing items, as well as environmental sustainability processes. Environmental concerns were more visible as public discussions of Shein often mentioned related topics like overproduction, waste generation, and the carbon emissions from international shipping. So, in conclusion, linking search terms for product quality with ultra-fast fashion implies that consumers are not just questioning the quality of products but also considering the environmental impact intertwined with it. Transparent logistics, including reporting carbon emissions, sustainable packaging methods, or green-shipping efforts, may become increasingly important as consumers identify perceptions about product quality with environmental and social sustainability issues overall.

What the behaviors suggest is a relatively sequential but prioritized process of information searching by the consumer. While explicit search terms reflect varying degrees of direct involvement (or lack thereof), price, quality, and logistics are not thought of in isolation but rather represent an interconnected "price-quality-logistics" nexus vis-à-vis consumers' perceived meaning. The lower relative Interest in "Shein shipping and customs duty" in accordance, despite its strong correlation with the other two terms, further confirms the point that logistical factors are usually considered as part of a broader assessment of value and purchase, not as a standalone paramount concern.

5.3. Ultra-Fast Fashion Implications for the Shipping and Customs Sphere

The findings highlight the important but largely invisible role of shipping and customs in allowing ultra-fast fashion companies like Shein to flourish. Despite lacking high-frequency explicit search, the high positive correlations and observed lead-lag dynamics suggest logistical efficiency; in addition, strong custom frameworks (de minimis laws, for example, Wang 2022) are quietly aiding the brand's core value proposition as expressed both affordably and in terms of trend readiness.

Spikes in Interest for the term "Shein prices" stem from supply chain processes, specifically intended to maximize efficiencies by minimizing landed costs through optimized shipping and robust customs procedures. Any disruption to the efficiency of logistical operations or movement, including changes in international trade regulations (e.g., adjustments to de minimis thresholds), could directly threaten Shein's ability to maintain its low-price-positioning strategy with potentially deep and immediate repercussions on actual consumer demand as indicated by search trends. As quality is largely product-centric, so too is the international delivery infrastructure that contributes to a user experience perception there (e.g., whether the item arrives intact or whether defective items are easy to return). Strategic investments in resilient packaging, reliable logistic partners, and clear returns procedures are no more than an expression of a brand promise for quality further up the delivery chain, where global e-commerce is concerned.

The low search volume in "Shein shipping and customs duty" could indicate an underlying consumer assumption that international delivery will happen reasonably smoothly without large hurdles. When those expectations are not met – through unreasonable lags, unanticipated surcharges hidden within the price of shipping, or vagaries in customs procedures – customers become indirectly dissatisfied with Shein's offer as a whole, and that Interest may fade when it comes to buying on account of prices (or quality), where logistics is often the behind-the-scenes cause. This highlights the paradox that logistics is rarely searched for directly, but its seamless execution remains vital to the perception of value in price and quality, which keeps consumers interested and engaged.

6. Implications and Future Research

The current research provides a detailed portrayal of how consumers connect their Interest in Shein's pricing and quality with questions around its international shipping and customs practices. They also suggest some potentially fruitful avenues for future research and have meaningful implications for theoretical development, managerial practice, and policy formulation.

6.1. Theoretical Contributions

The contribution of this research is to the literature on consumer behavior in e-commerce, especially in the ultra-fast fashion domain, by empirically validating the interdependence among product-centric attributes (price and quality) and logistical features (shipping and customs), as factors these consumers weigh during their information-seeking process. These outcomes are consistent with the previous literature on consumer decision-making and information search strategies (link goes here) (Bettman, 1979; Punj & Staelin, 1983), which indicates that purchase behavior comprises a direct function of both product evaluations and transaction-related factors. The lead-lag dynamic between "Shein prices" and logistical queries, therefore, suggests that the latter are indeed considered in a general risk assessment that influences the value perception process (Zeithaml, 1988; Grewal et al., 2004). The results based on Google Trends data and cross-correlation analysis support a novel behavioral interpretation of

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how these specific concerns unfold in public search behavior in a sequential or synchronous manner. It also reinforces a broad view of the value proposition whereby even peripheral logistical attributes that may be comparatively unimportant in the final consumer's mind indirectly impact perceptions of primary features like price competitiveness and product availability (Grewal et al., 2004). Moreover, this research reveals, in multiple ways, that Google Trends serves as a highly useful and timely measure of collective public sentiment and shifting behaviors over time in rapidly changing markets (Jun & Park, 2016; Vosen & Frömmel, 2011), warranting use in future studies.

6.2. Managerial Implications

The findings presented can be extremely beneficial for Ultra-fast fashion retailers. such as Shein and its competitors, providing various insights into what they could do next. It is not by accident that the firm interaction between price and quality interest presented means low prices' offers are insufficient as they must be supported by maintaining or even increasing the perceived quality level of the brand (which indeed remains crucial, in consumer engagement considerations). A consistent focus on a value proposition embedded with the notions of affordability and acceptable Quality standards should be part of marketing campaigns. Second, the temporal lag between "Shein prices" and "Shein shipping and customs duty" interest indicates that in price-based sales periods, better management of shipping timelines (and transparent communication about them) with adequate information regarding tracking, parcel details when shipped (Christopher 2016). To avoid future friction, retailers could deploy innovative tools to calculate customs duty and delivery-time estimates as well as provide real-time logistics updates that prominently display transparent information on shipping costs and estimated times. Also, simultaneously guiding clients on aspects like easy international returns (and policies regarding damages, both of which are outcomes of the shipping process) would do plenty of good for "Shein quality" inquiries. Finally, it is important to understand the optimization of global logistics, even though the general consumer would not Google this explicitly and might view it as merely an operational imperative, but rather a strategic lever that indirectly increases brand equity/retention.

6.3. Policy Implications

This paper makes an indirect thrust into the discourse of ultra-fast fashion and global trade policies. Since Shein's low-price model is primarily reliant on de minimis thresholds, which strengthen cross-border logistics (Wang, 2022; U.S. CBP, n.d.), a potential adjustment in the current trade setting could largely disrupt public interests through its impact on consumers' access to these goods. Given this, regulators considering amending de minimis regulations, for example, should be aware that these amendments may directly affect consumer prices and, more broadly, the entire e-commerce sector.

Over the past few years, different jurisdictions appear to have re-evaluated these frameworks, which reflects that policymakers are not simply debating reform in theoretical terms, but rather they are engaged in assessing and trialing actual changes to legislation, predominantly with a view to protecting domestic retailers and local enterprise from the competitive advantage, which unveils items sold by foreign sellers at present thresholds. As such, reductions in de minimis thresholds or more stringent customs procedures would inherently raise landed costs and delivery timelines, radically reshaping the core underpinning of cost advantage for Shein and other ultra-fast fashion retailers. For consumers, such changes may alter demand behavior in that they take some of the zing out of high shipping cost-driven purchases. Finally, and at a systemic level, these policy tweaks could lead companies to respond by avoiding behavior restrictions by developing regional distribution networks or adapting product strategies to meet tighter import controls.

This study provides empirical contributions to the debate on fair trade policies, environmental sustainability (regarding high shipping volumes), and labor standards in global value chains by examining the public attention regarding these interrelated factors and suggesting that economic and consumer welfare considerations should be symbiotically included in appropriate policy responses. It underlines that trade policy choices are not made in isolation, but linked to other areas: the consumer, brand, and ecosystem development in global e-commerce. Thus, subsequent regulators will have to re-evaluate their plans based on economic and competitive forces as well as social and consumer factors, which dictate how reforms should be processed in real life.

6.4. Limitations and Future Research Directions

This study has various limitations that highlight areas for future research. First, Google Trends data do not reflect the absolute search volumes or information on the demographics of who is conducting those queries. Thus, future studies may combine additional sources of data, such as social media analytics, sentiment analysis of online reviews, or survey-derived data, to triangulate findings and offer a qualitatively richer understanding of consumer search motivations.

Second, although the term "Shein shipping and customs duty" gives you a wider perspective of logistical Interest, it may fail to cover all the subtle queries related to it.

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In future works, logistic-related behaviors could be collected from even more specific search terms on a per-individual basis for shipping carriers, customs duties, delivery times, or international returns. Furthermore, situating the mode of dynamics against other ultra-fast fashion brands (e.g., Temu) would reassort the competitive context and deepen the generalizability of observed behavioral elements.

However, cross-correlation analysis may point to lead-lag dynamics but does not really prove causality because there is a high probability of spurious signaling. Future studies may use experimental designs or other more sophisticated econometric methods, such as Granger causality tests or vector autoregression models, to determine whether consumer concerns directly influence their purchasing behavior (or vice versa). Examining how external events (e.g., bombshell news stories, policy announcements) influence these search trends using event study methodology could also lend critical insight into how public Interest can suddenly spike or plummet.

7. Conclusion

This study has provided original empirical insight into the consumer behavior dynamics underpinning ultra-fast fashion, through a detailed analysis of global Google Trends data for “Shein prices,” “Shein quality,” and “Shein shipping and customs duty” over a 12-month period (August 2023 to August 2024). By applying time-series analysis, Pearson correlation, and cross-correlation methods, it has illuminated the previously underexplored relationship between consumers’ explicit Interest in core product attributes and the logistical infrastructure that enables global direct-to-consumer delivery.

The results clearly demonstrate that public search interest is primarily driven by Shein’s pricing and quality propositions, with a very strong positive correlation ($r = 0.94$) between these two dimensions confirming that consumers evaluate affordability and product standards as inseparable components of perceived value. Although direct search interest in “Shein shipping and customs duty” was comparatively lower, its positive correlations with both “Shein prices” ($r = 0.70$) and “Shein quality” ($r = 0.77$) reveal that logistical considerations, while less explicitly foregrounded, remain an integral part of the broader consumer value assessment.

The cross-correlation analysis contributes a key behavioral finding: price interest marginally precedes logistical Interest, indicating that price functions as the primary trigger that draws consumers into further inquiry about delivery feasibility and customs implications. Concurrently, quality and shipping interest move largely in tandem, suggesting that consumers assess product condition, returns accessibility, and delivery reliability as part of a unified quality evaluation rather than as separate concerns.

The central contribution of this study is its empirical demonstration that international logistics, specifically shipping efficiency and customs frameworks, such as de minimis provisions, are not merely operational background conditions but form an intrinsic and codependent part of Shein’s consumer value proposition. Any disruption to these logistical frameworks, whether through regulatory reform or operational failure, risks undermining the price and quality perceptions that sustain consumer engagement.

For practitioners, these findings reinforce the strategic importance of integrating logistics transparency into marketing communications, particularly during price-driven promotional periods. For policymakers, they underscore that trade regulation reforms, especially adjustments to de minimis thresholds, carry direct implications for consumer behavior and demand patterns in the global e-commerce sector. For researchers, this study establishes cross-correlation of public search data as a valid and productive method for mapping sequential consumer decision-making in digital-first retail contexts.

Future research should extend this framework by incorporating longer time horizons; brand-specific search terms for competitors, such as Temu, Zara, and H&M; and supplementary data sources, such as social media sentiment and transaction records.

The application of Granger causality tests and vector autoregression models would further strengthen causal inference. As the global e-commerce landscape continues to evolve, shaped by tightening trade regulations, growing sustainability expectations, and shifting consumer priorities, a holistic understanding of how product and logistical attributes jointly determine perceived value will be essential for both competitive strategy and evidence-based policy formulation.

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Investigating Challenges of Inventory Management in the Healthcare Sector

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Abstract

Purpose: *The purpose of this study is to investigate the challenges of inventory management within the public healthcare sector in Egypt. Therefore, it aims to identify and prioritize these challenges to establish recommendations for improving the effectiveness and efficiency of the "medical supply management".*

Design/Methodology/Approach: *The study employed a three-phase research design. First, a comprehensive literature review identified eight preliminary inventory challenges. Second, these challenges were validated through exploration interviews and a 5-point Likert scale survey with practitioners at the Public Children's Hospital, which resulted in the addition of two context-specific challenges. Finally, the Analytical Hierarchy Process (AHP) was used based on a pairwise comparison survey to rank and prioritize the identified challenges based on experts' judgments.*

Findings: *The research identified ten validated challenges affecting public hospital inventory systems. The findings of the AHP indicated that the "Stockout" remains the highest challenge with (25.2%), followed by "Limited Warehouse Space," which ranked (19.6%), and "Lack of Technology and Automation" with (17.4%). Other notable challenges included "Insufficient Staff Training" and "Overstocking.*

Research Implications/Limitations: *This study contributes to the literature by addressing a research gap regarding hospital inventory management solutions specifically tailored for developing countries. However, the findings are limited by their geographical focus on public hospitals within the Egyptian Governorate. Challenges may vary in other regions or different healthcare settings, such as private or specialized clinics, due to local administrative structures and resource availability.*

Practical Implications: *The study proposes actionable recommendations to improve inventory management performance, such as implementing Electronic Logistics Management Information Systems (ELMIS) and Warehouse Management Systems (WMS) to automate tracking and optimize storage. Enhancing these procedures can lower the operational costs of managing inventory, reduce medication waste, and consequently improve the quality of patient healthcare.*

Originality: *This research offers a novel application of the Analytic Hierarchy Process (AHP) to prioritize specific inventory management hurdles in the Egyptian public healthcare context. By mixing scholarly literature with the focus medical practitioner perceptions from a specialized children's hospital, the study provides a constructed and empirical framework for decision-making in resource-constrained settings.*

Keywords: *Hospital Inventory Management, Public Healthcare, Analytic Hierarchy Process (AHP), and Medical Supply Chain.*

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1. Introduction

The "Healthcare Logistics" in the healthcare industry engages in managing the flow of pharmaceutical and medical goods. Healthcare logistics are extremely complicated due to the high cost of items acquired and stored, as well as the unpredictability of demand associated with the fluctuating demands of patients. Given that this industry affects everyone's lives and is more than simply a business, a high degree of accuracy and a quick lead time must be ensured (Rathi et al., 2021). Therefore, effective inventory management has a positive impact on both the cost and the caliber of the healthcare services provided (Preziosa *et al.*, 2025). Specifically, hospitals' proper stock holding management has been acknowledged as a key factor in the efficacy and efficiency of their medical services (George and Elrashid, 2023). In developing countries, such as Egypt, their healthcare systems are currently facing such difficulties. However, Egypt's healthcare industry has seen the most severe economic downturn as a result of the national revolutions of the 1950s and the wars of 1967 and 1973. The Health Insurance Organization (HIO) Act, which embodies radical reforms, has caused the healthcare sector to suffer in previous decades. However, the present conflicts within Egypt have increased scarcity, poverty, and Lack of essential services, making inventory management a growing concern for public hospitals in Egypt. 9.6 million AIGAs and their families are insured by public hospitals, including 1 million health insurance cards, according to government reports. The benefiting citizens are eligible for free inpatient care, prescription drugs, lab testing, and curative therapy. Owing to the inadequate quality of care provided in public hospitals, these illnesses are highly prevalent and frequently require medication. Patients typically take eight different oral drugs on average each time they visit the pharmacy. Efficient inventory management in public hospitals is essential to guarantee the medical supplies' availability, as well as lowering the waste and providing the patients with high-quality care.

However, a lot of Egypt's public hospitals have issues with inadequate inventory control, including running out of necessary medications and discovering expired medications. The supply of public goods and the rectification of market imperfections, particularly for the most marginalized and vulnerable segments of society, serve as the primary rationale for the public sector's involvement in the healthcare system. The public sector clearly makes a considerable contribution, but inadequate inventory management plagues many public hospitals in underdeveloped nations, causing misery for the most vulnerable and impoverished patients. Public hospital managers in Egypt place a high premium on the effective and efficient administration of hospital stocks, which include medications, medical supplies, and medical equipment. Inventory control is critical to patient safety and is necessary for the timely and efficient delivery of healthcare services. Inadequate inventory control results in overstock, stockouts, expiration, and incorrect allocation. It results in both unfavorable reactions to expired medications and likely subtherapeutic pharmacological side effects. Inadequate management of hospital pharmaceutical inventory may raise drug prices and, in turn, lower the amount of money that the underprivileged Use for healthcare, resulting in higher out-of-pocket expenses. Public hospitals serve the impoverished and vulnerable, for whom these expenses represent a great sacrifice.

Egypt's public hospitals usually have serious challenges with their inventory management systems, which result in problems including shortages of necessary medical supplies, waste from overstocking or expiration, and ineffective use of resources. These challenges raise operating expenses, have a detrimental influence on patient care quality, and impair the healthcare system's overall efficacy. Therefore, this research aims to identify and prioritize the key challenges of inventory management in public hospitals in Egypt as a developing country. Furthermore, it seeks to develop actionable recommendations and potential solutions to address these challenges and provide enhanced efficiency and effectiveness in inventory management practices in hospitals. In order to achieve this research aim, the following objectives were identified:

1- To develop a structure for the identification of the challenges of the inventory management systems of public hospitals from previous literature and experts' opinions.

2- To rank these challenges according to their prioritization, using the Analytical Hierarchical Process (AHP).

3- To provide actionable recommendations and potential solutions to the most significant challenges of the inventory management systems of the Public Hospital in Egypt.

The next section will provide a comprehensive overview of existing literature relevant to the challenges of inventory management in healthcare settings. It includes the definition and the importance of inventory management in healthcare, the objectives of effective inventory management in hospitals, challenges identified in healthcare literature, and previous studies in the area of inventory management in hospitals.

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- **Inventory management in hospital management:**

The development of effective and efficient healthcare systems has become a critical subject due to the fast expansion in healthcare spending around the world and the corresponding rise in demand for healthcare services, of concern to policymakers in the government and the healthcare industry (Ahmadi-javid et al., 2017). The types of inventories in hospitals involve pharmaceuticals such as pills, capsules, and injections, as well as surgical and medical supplies.

syringes and surgical linen, sterile instruments, and medical equipment (X-ray machine, ECG machine, etc.).

Inventory management in hospitals focuses on efficiently handling supplies to meet both normal and emergency demands. It involves establishing policies for inventory levels, review frequencies, and safety stocks, ensuring quality patient care while minimizing costs and avoiding inflated inventories (Almehwari *et al.*, 2024). It enhances patient care, optimizes resource use, and improves customer relationships through effective logistic management techniques (Al Khatib et al., 2024). Moreover, inventory management in hospitals involves managing warehouses, inventory data, and medications to meet client demand. It requires balancing inventory costs with service expectations, particularly in operating rooms, while ensuring efficient supply chains without compromising quality or wasting resources (Alsuliman et al., 2022).

Efficient inventory management in hospital supply chains is crucial to prevent drug shortages (Zwaida et al., 2021). However, medical inventory management, unlike commercial supply chains, places a higher priority on time than cost due to the critical nature of patients (Aziz et al., 2024). Treatment delays are avoided, and healthcare outcomes are enhanced when necessary medical supplies, drugs, and equipment are readily available when needed, through effective inventory management. Moreover, it minimizes waste, prevents stockouts or overstocking, and maximizes resource use. Efficient inventory management is essential to ensuring the seamless operation of hospitals in a setting where prompt and precise care is essential.

Therefore, the inventory management system is a crucial component that influences the general and hospital systems' managerial and operational performance (Nsowah et al., 2025). Huge sums of money are invested in inventory at hospitals. In the event that supplies for treatments are delayed, cash flow issues could develop. However, an excess of inventory can also result in issues like expiration, deterioration of quality, and obstruction of limited resources. Therefore, efficient inventory management is essential as it aims to keep inventory levels as high as required to guarantee the quality of medical services, but as low as feasible to reduce the financial expenses related to holding, storing, handling, obsolescence, and damage loss. Because effective inventory management has a direct impact on the caliber of medical services rendered, both scholars and practitioners recognize the significance of this practice in hospitals.

- **Key components of efficient hospital inventory management:**

Hospital inventory management is essential to healthcare operations because it keeps costs down while guaranteeing that the goods are available. Procurement, Stock control, and Use of technology to increase productivity are all components of effective inventory management (Durmuş, 2023; Kartikasari,2024; and Syahidah et al., 2024). The main efficient components in hospital inventory management are:

A) *Strategies for Procurement:*

- Economic Order Quantity (EOQ): This methodology balances ordering and holding expenses to assist in identifying the ideal order quantity to reduce overall inventory costs.

- ABC Analysis: Hospitals can focus their management efforts on high-value items by using the ABC Analysis approach, which divides inventory into three classifications (A, B, and C) according to importance.

B) *Techniques of Stock Control:*

- Reorder Point (ROP): Setting a cutoff point for when to place new orders guarantees that inventory levels are kept in check without going overboard.

- VEN Analysis: This helps prioritize inventory management according to criticality by classifying things as vital, essential, or non-essential.

C) *Integration of Technology:*

- Predictive analytics and artificial intelligence (AI) improve forecasting accuracy and stock level optimization, which lowers waste and improves service delivery.

- RFID and IoT: These technologies make it easier to track inventories in real time, increasing

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visibility and lowering stock management errors.

Even though these procedures greatly increase the effectiveness of inventory management, issues still exist, such as public hospitals' limited funding and the requirement for ongoing staff training to accommodate new technologies (Setiawati et al., 2024).

- **Hospital Inventory Management Challenges:**

Inventory management in hospitals faces several challenges that may affect the quality of patient care, controlling costs, and the effectiveness of operations (Bekele et al., 2022). These challenges involve:

"Lack of automation and technology" indicates ineffectiveness, increased human mistakes, and errors in demand forecasting. This delays timely entrance to medical supplies, eventually affecting patient care and operational cost-effectiveness within healthcare organizations (Al Khatib et al., 2024).

"Lack of communication with vendors" is a problem, as hospital inventory management requires effective vendor communication, but there are several obstacles that prevent operational effectiveness. The absence of real-time data sharing between hospitals and vendors is one of the main problems leading to stockouts. Stockouts or overstock consequences are regularly caused by this restriction, which frequently leads to out-of-date inventory records (Sharma, 2015).

"Insufficient training of staff" in hospital inventory management substantially affects the productivity of healthcare supply management. This implies that ineffective training practices lead to poor inventory management, resulting in stockouts and resource wastage (Krishnakumar et al., 2023). This issue is compounded by a lack of standardized procedures and insufficient knowledge among staff involved in managing the inventory management systems (Rodgers & Desderio, 2020).

"Stockouts" happening is generally identified as one of the most disruptive challenges within healthcare supply chain management, as it has occurred intensively in public sectors of developing economies. It occurs generally when the inventory of a specific medical element is depleted, which leads to a "backorder" setting that hinders the flow of hospital operations. Unlike conventional retail sectors, a stockout in healthcare is not purely a lost sale but a critical risk to patient protection that can lead to increased illness and death rates (Kwon et al., 2020).

"Overstocking" describes having extra medical equipment, supplies, and medicines than is required for regular operations. The stockout harmfully affects overall patient care, waste minimization, and cost efficiency (Khashu et al., 2025). Not only can overstocking result in financial losses, but it can also result in increased expenses for storage and obsolescence, as well as poorer customer satisfaction (Zwaida et al., 2021).

"Limited warehouse space"**:** the efficacy of pharmaceutical storage and inventory management is severely hampered by hospitals' limited warehouse space. This limitation may result in inefficiencies, raise the possibility of deterioration of drug quality, and ultimately have an impact on patient care (Al Armoti & Alkabi, 2019). Moreover, insufficient warehouse space might cause drug buildup and complicated logistics, raising the possibility of mistakes and delivery delays.

"Supply Chain Problems" have a major impact on hospital inventory management, which can seriously compromise patient care and operational effectiveness (Zwaida et al., 2021). All the partners of the supply chains of healthcare service, such as managers of healthcare, manufacturers of pharmaceuticals, distributors, information service providers, and even service consumers, are just a few of the many stakeholders that must be coordinated due to the complexity of the healthcare supply chain (Kefale et al., 2019). Variations in demand, supplier constraints, and regulatory obstacles all contribute to the complexity of handling medical supplies, especially medicines. To reduce these problems and guarantee that hospitals can continue to deliver care, effective inventory management techniques are crucial (Bafarat et al., 2025).

"Ineffective procurement process", as one of the main obstacles to the efficient management of the necessary inventory of medicines, is the procurement process. Delays in the procurement process, mostly locally, result in frequent stockouts of essential medications, especially at the health post level (Id *et al.*, 2024).

As shown in the above exploration of the challenges affecting inventory management in hospital logistics management in the current literature, eight main challenges have been identified. These challenges may hinder the efficacy of the management process of the related inventory of hospitals' logistics management. In the next section, the recent studies in the field of inventory management in the healthcare sector within developing countries will be explained.

- **Previous studies about Hospital Inventory Management:**

A critical review of the current literature regarding

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inventory management at public hospitals shows a clear polarization between highly advanced quantitative optimization models and the practical resource limitations of developing countries. On one hand, broad global research focuses on complex algorithmic approaches, such as the Deep Reinforcement Learning (DRL) model for drug refilling decision-making (Zwaida et al., 2021), Statistical Process Control (SPC) methodologies (Eissa & Rashed, 2020), and discrete event reproduction for surgical instruments tracking (Bhosekar et al., 2020; Nallusamy et al., 2018). However, Volland et al. (2017) categorize inventory management as a key research stream in hospital material logistics, emphasizing optimization techniques; it does not specifically address inventory management practices in developing countries, focusing instead on literature from industrialized nations. Moreover, Bialas et al. (2020) implemented empirical testing of a framework for improving hospital inventory management at a large public hospital, demonstrating that the Lack of data availability and unstable infrastructure conditions are rarely present in the public health care sector in developing countries.

While literature explicitly focuses on developing countries, studies have depended on traditional mathematical data segmentations or basic descriptive surveys. For example, several scholars heavily encouraged ABC, VEN, and SDE matrix classifications to manage hospital inventory costs and prevent stockouts (Durmuş, 2023; Ladjama et al., 2024; Legese et al., 2022; Mohammed & Workneh, 2020). While these categorization tools are useful, practical field studies across public sectors in developing countries like Kenya, Namibia, and Ethiopia reveal that root cause inventory management weaknesses are hardly just mathematical; relatively, they are extremely rooted in human and structural shortages, such as budget shortages, insufficient staff capabilities, and a lack of standard computerization (Dikire & Gemeda, 2024; Shibabaw et al., 2023; Odanga & Wachiuri, 2022). Furthermore, while Lean thinking (LT) methodology or implementing Vendor-Managed Inventory (VMI) showed successful management results, public hospitals normally neglect these strategies due to systemic risks and a lack of administrative commitment (Krichanchai & McCarthy, 2017; Gurumurthy et al., 2021).

Accordingly, a serious gap remains, as existing scholars either offer high technological solutions that developing countries' public hospitals cannot implement, or scholars who describe systemic failures without a structured and prioritized path. Therefore, this study addresses this gap by contextualizing these intersecting operating and technical inventory management challenges within a public pediatric healthcare system in Egypt as a developing country. By utilizing a multicriteria decision-making approach named AHP, this study moves beyond simple descriptive summaries to quantitatively prioritize these challenges, developing an actionable and specified roadmap for the public healthcare system for improving inventory management.

2. Methodology of the Study

The methodological process of this study concludes 4 phases. **In phase 1**, a literature review is conducted to identify the challenges of inventory management in hospital management. Therefore, scholarly work, studies, and publications pertaining to inventory management strategies were used to create a preliminary list of 8 challenges. **Phase 2** was focused on validating the practical reality of the proposed list of challenges. Interviews are conducted with inventory management practitioners from the Public Children's Hospital to gather their insights and perspectives. Firstly, the practitioners were asked to rate the proposed list of challenges using a 5-point Likert Scale to confirm which of these challenges they are already facing. Secondly, the practitioners were asked to recommend any additional challenges that were not initially identified in the literature review. In fact, the practitioners recommended 2 challenges to be added to the list; the list was updated to include 10 challenges. **Phase 3** involved prioritizing the barriers. A pairwise comparison questionnaire was conducted with the practitioners of inventory management at the Public Children's Hospital. The participants were asked to compare the significance of the identified 10 challenges against each other. The Analytic Hierarchy Process (AHP) technique was then used to prioritize the challenges based on the responses obtained from the pairwise comparisons. The AHP technique helps assign relative weights or priorities to each challenge. A Pairwise Comparison Matrix was presented for the identified challenges in a series of pairwise comparison matrices. For each pair of challenges, respondents were kindly asked to indicate which challenge was more important and by how much, using Saaty's 9-point fundamental scale of relative importance (1 = equally important, 3 = moderately more important, 5 = strongly more important, 7 = very strongly more important, 9 = extremely more important, with even numbers for intermediate values).

To achieve the aim of this research, the primary case study was conducted at the Public Children's Hospital. The hospital is a specialized public pediatric facility located in Egypt, operated under the jurisdiction of the Egyptian Ministry of Health and Population. The hospital maintains an operational capacity of approximately 50 inpatient beds, a highly specialized 34-cradle Neonatal Intensive Care Units (NICU), Pediatric Intensive Care Units (PICU), and an early intervention and rehabilitation center for special needs children. The selection of

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this hospital is greatly appropriate to healthcare logistics management because of its high demand and specialized inventories of medical commodities, pharmaceuticals, and life-support consumables. Furthermore, as it is considered a public institution supplying necessary subsidized healthcare to a large geographic regional demographic, it operated under complicated institutional administrative structures. This makes it an ideal testing ground for evaluating inventory management challenges.

The research design for this study was descriptive and analytical, specifically focusing on a case study approach focused on the Public Children's Hospital. Descriptive, as it describes the challenges of hospital inventory management, and analytical, as it analyzes the prioritization of such challenges using the AHP technique. A purposive sampling technique was utilized to select four key experts (the Inventory Manager, two Hospital Storekeepers, and a Supply Chain Manager) directly handling medical supply chain operations at the Public Children's Hospital. While a sample size of four might appear small for empirical surveys, the AHP is explicitly designed for small, expert-driven groups rather than large representative samples (Nguyen *et al.*, 2022). The AHP relies profoundly on the qualitative depth, specialized domain knowledge, and precise professional judgment of the participants rather than statistical generalizability (Saaty, 1990). Methodological accuracy is instead verified through the mathematical consistency of the aggregated matrix, which in this study yielded a valid Consistency Ratio (CR) of 2.10%, well within the universally accepted threshold of less than 10% (Saaty, 1990).

Their selection was based on their extensive experience and critical roles within the hospital's supply chain and inventory management functions, including an Inventory Manager with 20 years of experience, a Supply Chain Manager with 15 years of experience, two Hospital Storekeepers with 15 and 10 years of experience respectively, and a Supply Chain Officer with 3 years of experience. While the experts had different years of experience, they all met the eligibility criteria of the study, ensuring that every expert had the standard expertise required to evaluate the challenges in the pairwise comparison.

To capture a balanced and comprehensive framework, the pairwise comparison data for AHP were generated in a focus group using the "Consensus-Seeking Approach". In AHP decision-making, following the Consensus-Seeking Approach by engaging an expert panel in a focus group discussion allows participants to debate and reconcile different perspectives openly, making the methodology more robust (Dong and Saaty, 2014). Consequently, all experts' judgments were equally weighted in the focus group. There are many software packages on AHP; in this study, Expert Choice, which is one of these software packages on AHP, was used. Using Expert Choice, the user can graphically adjust the weights of the decision criteria and see on screen how the alternatives' rankings will change.

3. Study Findings

As stated before, a two-stage survey approach was employed to identify and prioritize the challenges of inventory management in public hospitals. A preliminary list of eight challenges was identified via literature review and validated by four key hospital practitioners using a 5-point Likert scale. All eight challenges were confirmed with mean scores above the average. However, the challenges "Lack of technology and automation" and "Limited warehouse space" had the highest mean score, 5.00.

Additionally, the participants identified two challenges: "Limited Budget and Resources" and "Poor Communication between Departments". They defined them from the operational perspectives as:

- Limited Budget and Resources: The financial and structural constraints that limit capital investment in modernizing supply chain systems, consequently, affect inventory management systems. Moreover, these constraints limit the expansion of physical storage infrastructure.

- Poor Communication between Departments: The fragmentation and delay of critical data flow and operational alignment between independent departments, such as clinical departments, procurement departments, and inventory management, result in a lack of real-time visibility, which affects the overall inventory management process.

Lastly, the practitioners finalized a list of 10 challenges for prioritization using the AHP technique as the last step of the methodological process. The AHP was utilized to prioritize the validated challenges using a pairwise comparison by the same practitioners from the Public Children's Hospital. Geometric means have been used as the aggregation approach to combine the experts' judgments, according to the AHP technique. The results showed that the CR= 2.10 %. This percentage is accepted, as Saaty (1990) has shown that a CR of 10% or less is acceptable to continue the AHP analysis. If the consistency ratio is greater than 10%, it is necessary to revise the judgments to locate the cause of the inconsistency and correct it. Table 1 summarizes the AHP priority, weights, and geometric mean results.

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Table 1 Inventory Challenges Priorities:

Challenges	Geometric Mean	Priority	Rank
1. Stockout	3.8967	25.2%	1
2. Overstocking	1.0827	6.9%	5
3. Limited Warehouse Space	2.6288	19.6%	2
4. Lack of Technology and 5. Automation	2.2694	17.4%	3
6. Lack of Communication with Vendors	0.8013	6.8%	6
7. Insufficient Training Staff	1.0827	7.1%	4
8. Poor Communication between 9. Department	0.7618	5.4%	7
10. Ineffective Procurement 11. Process	0.5250	4.6%	8
12. Limited Budget and Resources	0.4138	3.4%	10
13. Supply Chain Problems	0.4137	3.5%	9

Top Priorities:

- Stockout (25.2%): This is clearly identified as the most critical challenge, holding the highest priority. This suggests that the inability to meet demand due to a lack of stock is perceived as the most significant problem.
- Limited warehouse space (19.6%): Ranked second, this indicates that physical constraints on storage are a major concern, potentially hindering efficient operations and contributing to other issues.
- Lack of technology and automation (17.4%): As the third priority, this highlights a recognition of the need for modernization and technological advancements to overcome existing challenges.

Mid-Range Priorities:

- Insufficient training staff (7.1%) and Overstocking (6.9%) follow, indicating these are also important, though less so than the top three. The relatively close priority of overstocking to stockout might suggest a perceived challenge in balancing inventory levels.

Lower Priorities:

- Challenges such as Lack of communication with vendors (6.8%), Poor communication between departments (5.4%), Ineffective procurement process (4.6%), Supply chain problems (3.5%), and Limited budget and resources (3.4%) are ranked lower. While still challenges, their perceived impact is considerably less than the top issues. “Limited budget and resources” being the lowest priority is interesting; it might imply that the respondents believe solutions to other problems are achievable even within current financial constraints, or that the other problems have a more direct and immediate impact.

4. Discussion

In this section, some recommendations are presented to overcome the three top-priority challenges found by AHP analysis. These are Stockout, Limited warehouse space, and Lack of technology and automation. Regarding “Stockout”, which revealed the top priority in hospital inventory management, it poses a serious problem since they have an immediate effect on the capacity to satisfy patient demand and guarantee the provision of high-quality healthcare. This finding confirmed the results of Jayani & Pudjirahardjo (2014), which identified stockout as a significant issue, with a recorded occurrence of 33.4% in hospital inventory management. Also, the findings reflect a study finding by Kabera & Mukanyangezi (2024), as they mentioned that stockouts that result in an inability to satisfy demand are seen as a serious issue since they can have serious repercussions, including worsened patient care and higher death rates. Inadequate supply chain systems and ineffective inventory management techniques make this problem worse. Recommendations to overcome stockouts: (1) Advanced Inventory Systems: According to Kabera and Mukanyangezi (2024), putting in place advanced inventory management systems, including electronic logistics management information systems, can greatly lower stockout rates and increase stock availability, (2) Effective Supply Chain Management: Stockouts can be avoided and overall inventory efficiency raised by streamlining supply chain procedures, such as sourcing tactics and waste minimisation (Kachwee & Hartmann, 2013), and (3) Emergency Inventory Planning: To ensure preparedness for unforeseen spikes in demand, hospitals should create inventory plans that take into consideration both regular and emergency demand conditions.

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Regarding the challenge "Limited warehouse space", which accounts for 19.6% of issues, it has a big influence on how well inventory is managed. This limitation of the warehouse space may result in operational inefficiencies, higher expenses, and difficulties in satisfying patient requirements. This confirmed the study of Abideen et al. (2024, which mentioned that Space constraints might result in haphazard storage, which makes it challenging to find essential supplies fast, particularly in an emergency. This may lead to drug mistakes, therapy delays, and compromised patient safety. Recommendations to overcome Limited Warehouse Space: (1) Redesigning Layouts: Efficient engineering must re-evaluate the current warehouse layout to improve flow, create dedicated zones (e.g., for sterile vs. non-sterile, high-volume vs. low-volume, cold storage), and potentially narrow aisles with specialized equipment (Automatisés *et al.*, 2023), (2) Warehouse Management System: FEFO/FIFO (First-In, First-Out) rules, put-away and picking optimisation, real-time inventory tracking, and expiration date management are all possible with warehouse management systems (Owino et al., 2013). This significantly improves control and visibility, enabling more accurate stock levels and minimizing the need for more physical space.

About the challenge "Lack of technology and automation," it ranked as the third top priority of the challenges. The finding reflects a study by Papadopoulos et al. (2021), which mentioned that manual ordering, receiving, and inventory monitoring procedures are labor-intensive, time-consuming, and prone to human mistakes. This led to inaccurate stock levels, lost goods, and delays resulting from this, all of which raise operating expenses and reduce output. Recommendations to overcome "Lack of technology and automation": (1) Warehouse management system: It is important as it updates receipt and delivery, optimizes storage locations, automates inventory tracking, and facilitates accurate picking procedures. This immediately decreases errors and increases space utilization (Soegoto and Nugraha, 2020). (2) Barcoding and RFID (Radio-Frequency Identification): Real-time tracking from receipt to point-of-use is made possible by the Use of barcode and RFID scanning devices for all medical supplies. This significantly lowers the amount of manual counting, increases inventory accuracy, guards against loss, and makes automatic reordering easier (Papadopoulos et al., 2021). (3) Enterprise Resource Planning (ERP) Systems: By combining a WMS with a more comprehensive ERP system, data can move smoothly between the financial, clinical, procurement, and inventory departments, giving a comprehensive picture of the supply chain and enhancing planning in general (Islam and Shorif, 2025).

According to the study results, it is highly counterintuitive that the expert panel ranked 'Limited budget and resources' as the lowest priority challenge (10th, 3.4%). Far from implying that financial capital is abundant, this significant finding reveals a critical strategic paradigm shift among healthcare practitioners. However, the participants argued that operational challenges, specifically 'Lack of technology and automation' (3rd, 17.4%) and 'Poor communication between departments' (7th, 5.4%), represent initial deficiencies that severely reduce the return on investment of any subsequent financial investment if mismanagement is left. Accordingly, they placed technological and structural optimization as a fundamental requirement to increase funding. For instance, if the hospital receives a budget increase but at the same time lacks automated inventory tracking or interdepartmental data synchronization, the additional budget will be misallocated. Therefore, the AHP evaluation indicates that prioritizing building robust, visible, and automated inventory management over budget growth is necessary.

5. Theoretical Implications

This study expands the theoretical limitations of healthcare logistics and multicriteria vulnerability assessment in multiple dimensions. Firstly, it addresses a significant gap in the scholarly literature by redirecting the emphasis from generalized, resource-abundant private medical institutions to highly specialized public pediatric facilities situated in developing nations. Secondly, the study results reveal that technological and communication-based challenges are overlooked financial challenges in public health systems. Accordingly, this study improves the Resource-Based View (RBV) within the supply chain concept, particularly inventory management. Rather than inspecting financial investment as the primary driver for organizational resilience, the study's empirical ranking exposes operational hierarchy where digital structure (Lack of technology and automation) and rational infrastructure (Poor communication between departments) are seen as initial capabilities.

This introduces a novel framework for prioritizing the challenges of inventory management within public sector healthcare facilities, as the augmentation of financial resources does not necessarily enhance operational efficiencies; instead, it is the "preparedness" in operational and technological dimensions that determines the capacity for engagement and the effectiveness of financial resources.

6. Practical Implication

These study findings provide practical implications for the healthcare sector at two levels: the public hospitals and the Health Insurance Organization (HIO). At the

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hospital level, the administrators should focus on handling the main challenge of "Stockouts" as they should utilize better communication management between medical departments, procurement departments, and storage departments to predict early demand. Furthermore, the current "Warehouse Space" must be physically rearranged to optimize the "Limited Warehouse Space".

At the HIO level, it should model a strategic investment. Due to the high rank of "Lack of Technology", the HIO should implement a gradual technology implementation with barcode tracking or life-saving pediatric goods. This must be supported by "Staff Training" to ensure a successful long-term system.

7. Conclusion and Future Work

This study identified and prioritized the major inventory management challenges of the Public Children Hospital, providing a clear roadmap for public healthcare logistics in developing countries such as Egypt. The findings of the AHP assessment of these challenges reveal that the operational risks, such as "Stockouts", "Limited Warehouse Space", and "Lack of Technology and Automation," are the true root cause of the logistics weakness, particularly the inventory management. Critically, the lowest ranking of "Limited Budget and Resources" confirms that arranging financial resources at a structurally failed system will not fix it; instead, establishing process visibility and communication must come first. Resolving these logistical challenges will have a direct impact on patient care and the wider Egyptian healthcare system. At the hospital level, reducing medication stockouts ensures successful patient care services without dangerous delays.

This study focused on a specific Public Children's Hospital in Egypt. Future research could expand the scope to include multiple public hospitals across different regions or with varying scales of operation in Egypt. A comparative study would help to identify whether these challenges and their prioritization are consistent across the public healthcare sector in developing countries, or if there are unique challenges or variations based on hospital size, location, or specialization. This could lead to more generalized recommendations and policy interventions.

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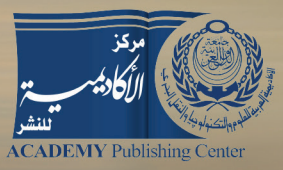

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