Supply Chain management for port performance enhancement based on Artificial intelligence

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Abstract

Egypt faces a series of challenges and opportunities in developing its supply chain management (SCM) and port operations. These developing include technological infrastructure expansion, digital transformation, regional integration and social responsibility. Artificial Intelligence (AI) is emerging as a solution for (SCM) to meet this challenges and achieve optimal performance. This study suggests that the integration of Artificial Intelligence (AI) in SCM aims to improve port performance in Egypt, based on the results of the questionnaires. However, this integration remains insufficient as it faces several obstacles, including the variability of AI maturity among supply chain actors, data security concerns, and the need to develop specialized skills in AI. Specifically, the findings of the study were analysed in relation to the existing literature and their relevance to the research objectives and questions. The purpose of this research paper is to provide a summary of the findings and conclusions, as well as the limitations and potential contributions of the research.

Keywords: supply chain management(SCM), Digital transformation, Artificial Intelligence(AI), Port performance.

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إدارة سلسة التوريد لتحسين أداء الموانئ بالإعتماد على الذكاء الإصطناعي

الملخص

تواجه مصر سلسلة من التحديات والفرص في تطوير إدارة سلسلة التوريد وعمليات الموانئ. ويشمل هذا التطوير التوسع فى البنية التحتية التكنولوجية، والتحول الرقمي، والتكامل الإقليمي، والمسؤولية الإجتماعية. يظهر الذكاء الاصطناعي كحل لادارة سلسلة التوريد . تشير هذه الدراسة إلى أن دمج الذكاء الاصطناعي في إدارة سلسلة التوريد يساهم في تحسين أداء الموانئ في مصر، بناءً على نتائج الاستبيانات. ومع ذلك، لا يزال هذا التكامل غير كاف لأنه يواجه العديد من العقبات، بما في ذلك تباين نضج الذكاء الاصطناعي بين الجهات الفاعلة في سلسلة التوريد، والمخاوف المتعلقة بأمن البيانات، والحاجة إلى تطوير مهارات متخصصة في الذكاء الاصطناعي. وعلى وجه التحديد، تم تحليل نتائج الدراسة فيما يتعلق بالأدبيات الموجودة وصلتها بأهداف البحث وأسئلته. الغرض من هذه الدراسة هو تقديم ملخص للنتائج والاستنتاجات، فضلا عن القيود والمساهمات المحتملة للبحث.

الكلمات المفتاحية: إدارة سلسة التوريد, التحول الرقمى, الذكاء الإصطناعي, أداء الموانئ.

Introduction

Artificial intelligence (AI) is an advancing discipline with the capacity to revolutionize various domains of business and society. This field allows robots to do tasks such as perceiving, analyzing, acquiring knowledge, solving problems, and making decisions, which are commonly linked with human intelligence [1]. However, the advantages of AI extend beyond than only this; it can also enhance human capabilities, leading to significant improvements in productivity, efficiency, and innovation [2].

AI adoption in specific industries offers advantages in supply chain management (SCM) [3]. (SCM) supply chain management, is the practice of arranging, controlling, and overseeing the flow of goods, information, and services from the supplier to the customer. This function not only enables the collaboration of various stakeholders such as suppliers, manufacturers, distributors, retailers, and customers, but also includes a wide range of tasks such as inventory management, transportation, warehousing, and manufacturing. The complex and constantly changing supply chain management system faces various key challenges, including unpredictability, risk, competition, sustainability, and uncertainty [4].

Artificial intelligence (AI) is recognized as a viable solution for supply chain management (SCM) to tackle these challenges and attain optimal efficiency by leveraging data-driven information access, optimized decision-making, automated procedures, and collaborative promotion. Moreover, artificial intelligence offers fresh perspectives that can yield substantial advantages to the field of supply chain management. These encompass untapped possibilities for personalization, differentiation, tracking, and

sustainability. Artificial intelligence (AI) can significantly enhance supply chain management (SCM) by enhancing resilience, efficiency, agility, and innovation [5].

Port operations play a vital role in overseeing the manufacturing ecosystem. Ports play a crucial role in linking various types of transportation, enabling the smooth flow of products between countries and regions. Their function in determining global trade dynamics and promoting economic growth is significant [6]. Nevertheless, ports encounter a multitude of complex operational challenges including congestion, delays, safety risks, environmental consequences, security threats, and compliance with regulations. To preserve their performance, ports must augment their capacity, productivity, reliability, quality, and sustainability to accommodate the growing demands of their vital function in global supply chains. The user's input is [7].

Literature review

According to [8] the study contributes to the existing knowledge by offering practical implications for AI integration in supply chains, highlighting the significance of managing constraints and industry heterogeneity. By identifying and understanding the key constraints, this research provides a deeper understanding of the constraints faced during different stages of AI in supply chains. This study makes a substantial contribution to the current socio-technical discourse on the successful journey of AI in supply chains by deriving eight propositions that offer valuable insights. These propositions delve into the practical implications of addressing constraints and transforming them into enablers for achieving enhanced

supply chain performance. The propositions offer guidance to both academic researchers and industry professionals, equipping them with actionable strategies to navigate the complexities and intricacies of integrating AI technologies into the supply chain. By embracing these propositions, stakeholders can effectively harness the power of AI to optimize various aspects of the supply chain, leading to improved efficiency, agility, and competitiveness. Ultimately, this research contributes to advancing the understanding of the AI journey in supply chains and offers practical solutions to drive the successful embracing of AI technologies in real-world supply chain environments.

[8] Tried to implement a methodology for measuring port performance. They first relied on previous literature. Then, they used a multi-criteria decision analysis to operationalise the context of port choice by presenting a weighted approach. Their sample includes 7 ports operating in Europe (Rotterdam, Antwerp, Hamburg, Koper, Piraeus, Genoa and Gdansk) and five hinterland destination regions (Southern Germany, Switzerland, Austria, Czech Republic and Hungary). The study shows that the most important factors determining the competitiveness of ports are the cost and time of the transport chain.

Similarly, [9] attempted to quantify and analyse the efficiency of 24 Brazilian ports (19 public ports and 5 private terminals) during the period between 2010-2017. The results of the DEA technique and Principal Component Analysis (PCA-DEA) suggested the existence of low efficiency of these ports, resulting from governance and infrastructure problems. In addition, they showed that the efficiency (or quasi-efficiency) frontier obtained generates good performance results. The study

shows that the main obstacle that hinders ports from being efficient is the parallel infrastructure (i.e. waterways and

railways that are scarce and lack significant investments). The conclusion reached by the author is that land infrastructure problems require public investment, as concessions attract more private interest, such as fully developed motorways near major centres. It is then necessary to install secondary roads until the cargo reaches its final destination through well-structured roads.

As for weak AI, it focuses on solving specific problems using human-like approaches. Reasoning, adaptation, learning and social intelligence are key elements used by computer programs to solve particular problems. Speech or text recognition is the right illustration. In fact, standard AI aims to offer intelligent algorithms somewhere in the software. In contrast, strong AI aims to embody intelligence in robot-like machines and make them behave intelligently. Nowadays, the two types of AI blend together as AI is designed to make machines smarter and to produce intelligent machines [10].

AI research includes various intelligent information processing techniques. These different methods include perception, learning, planning, knowledge, reasoning, and communication and offer in particular in the field of robotics machines and computers that are likely to behave in, interact with and participate in the real world. For this reason, AI mainly employs symbolic techniques namely decision trees, logic and knowledge-based methods, stochastic automata and case-based reasoning. These methods make it possible to draw logical conclusions or states of automata [11].

In a more recent study, [12] chose the Egyptian context to assess the extent to which Egyptian ports can apply smart practices and use technology to achieve and improve sustainable port performance. They conducted a survey using interviews with a group of 10 different stakeholders from government, private sectors, and experts in the field of port management. The results of this study revealed the existence of some challenges and obstacles that hinder the adaptation of sustainable technology and practices in Egyptian ports. They also indicated the need to adopt new procedures to facilitate the development of smart practices and the application of technology in Egyptian ports in order to maximise their sustainable performance from different perspectives (economic, social and environmental).

The main purpose of this study is to examine the integration of AI into SCM and port operations, highlighting the specific context of Egypt. Egypt occupies a strategic position in world trade, as a crossroads linking the continents of Asia, Europe and Africa via the Suez Canal. The country is also home to several major ports that play a crucial role in handling a considerable volume of goods and passengers. However, Egypt also faces a series of challenges and opportunities in developing its supply chain management and port operations. These include technological infrastructure expansion, digital transformation, regional integration and social responsibility.

Research Aim and Objectives and Questions

This study explores the impact of AI on SCM and port operations, aiming to improve operational, financial, environmental and social performance. It examines the challenges and opportunities related to the integration of AI, proposes appropriate strategies and recommends technologies

to optimise the port supply chain in Egypt. The study adopts a methodological approach, quantitative (questionnaires) method to obtain a comprehensive perspective of the stakeholders involved. In order to achieve the main objective of this study, the following specific objectives have been formulated:

a) To examine the current and potential applications of AI in SCM and how they can improve port performance in terms of operational, financial, environmental, and social aspects.
b) To explore the key challenges and opportunities associated with implementing AI technologies in supply chain and port operations, and to propose effective strategies and solutions for managing them.
c) Identify and recommend the most appropriate AI technologies to improve the port supply chain in Egypt.

After outlining the purpose and goals of this research, the objectives are subsequently reformulated into research questions. These questions serve to elucidate the specific areas of inquiry and provide a clear direction for the investigation and findings of this study. The research questions (RQ) are listed below:

RQ1: To what extent does the use of artificial intelligence in supply chain management improve port performance?
RQ2: What are the key challenges and opportunities associated with implementing AI technologies in supply chain and port operations, and how can these be effectively managed?
RQ3: What are the most appropriate AI technologies to improve the port supply chain in Egypt?

Research Contribution

This study undertakes to make the following contributions:

- Propose a comprehensive literature review that explores the multiple facets of AI applications in supply chain management and port operations.

- Highlight current practices and trends in the use of AI in supply chain management and port operations, both globally and in Egypt.

- To provide a comprehensive literature review that explores the multifaceted applications of AI in supply chain management and port operations.

- Highlight current practices and trends in the use of AI in supply chain management and port operations, both globally and in Egypt.

- Assess the proven impact of AI on critical performance indicators within ports, such as throughput, quality of service, safety, security, efficiency, profitability and sustainability.

- Probe barriers, drivers, enablers, best practices, lessons learned, and map out future perspectives related to the implementation of AI technologies in supply chain management and port operations.

- Develop a structured framework for the selection and evaluation of the most relevant AI technologies to improve the port supply chain in Egypt.

Research Method

Firstly, gather the necessary data, our research utilizes quantitative method. We distribute questionnaires with Egyptian respondent. The questionnaire is designed for Logistics and supply chain professionals (working in port companies, freight forwarders, logistics service providers or other organisations related to the port supply chain), technology and artificial intelligence experts (working in companies related to logistics, IT, or information technology), Researchers and academics (working in the fields of logistics, supply chain and AI), providers of AI technologies and port supply chain management solutions. The questionnaire focuses on several main themes including the reasons for the application of AI technologies in the port supply chain, key challenges and opportunities associated with implementing AI technologies in port supply chain, and main AI technologies to improve the port supply chain. The questions in the questionnaire are formulated in a simple and easy-to-understand manner to ensure respondents can answer them effectively.

Their number is determined to be about (510) people, and these questions were derived through a large review of the intellectual heritage on this topic and a wide knowledge of previous studies, in addition to the researcher's experience and reliance on his thought in this. The field where these questions are not borrowed from any previous research, study, or questionnaire.

Part 1: General Characteristics

This part will tackle the research sample socio-demographic characters of the selected sample, the following table is an

overview of the characteristics of the participants in terms of frequency and percentage.

Table (1): description of demographic characteristics among survey participants (n=510)

Variable	*Frequency*	*Percentage*
Gender		
female	92	18%
male	418	82%
Age		
under 30 years old	82	16.1%
from 30 to 40 years old	138	27.1%
from 41 to 50 years old	208	40.8%
more than 50 years old	82	16.1%
Educational Level		
Higher diploma	35	6.9%
Bachelor's degree	317	62.2%
master's degree	92	18%
PhD degree	66	12.9%
Administrative Position		
director of department	90	17.6%
unit director	140	27.5%
head of department	143	28%
consultant	84	16.5%
any other position	53	10.4%
Work Experience		
less than 5 years	83	16.3%
from 5 to 10 years	121	23.7%
from 11 to 20 years	117	22.9%
over 20 years	189	37.1%
Affiliation of Institution		
governmental public sector	215	42.2%
private sector eligibility	295	57.8%

Part 2: Reasons for the Application of AI Technologies in Port Supply Chain

Descriptive Statistics

This subsection will tackle the descriptive statistics of the questions involved in the second part of the questionnaire through presenting the frequency and percentage of each selected answer.

Table (2): description of the questions involved in the second part (n=510)

Variable	*Frequency*	*Percentage*
Potential Benefits of AI Technologies in Port Supply Chains		
improved efficiency	334	65.6%
reduced costs	309	60.6%
increased safety	297	58.2%
better environmental performance	130	25.5%
Optimization of Port Performance		
cost and complexity	293	57.5%
data quality and security risks	391	76.7%
job displacement	162	31.8%
lack of transparency	188	36.9%
Effect of AI Technologies on Various Stakeholders		
improved supply chain visibility	177	34.7%
predictability through AI-powered logistics planning	341	66.9%
and predictive analytics	271	53.1%
potential job displacement as certain tasks become automated	198	38.8%
potential disruptions during the implementation of new AI technologies		
Optimization of Supply Chain Management Processes within Ports		
improved predictive maintenance	321	62.9%
improved decision making	388	76.1%
better resource allocation	177	34.7%
improved risk management	315	61.8%

The sum of the percentages is not equal to 100% as these questions allow multiple choices.

Creating Indicators

In the second part, 4 indicators will be created. These created indicators are presented in the row form of Table (2).

Reliability Analysis

Cronbach's Alpha reflects a good reliability of the research questions as its values range from 0.716 to 0.979 for the constructs which exceeded the threshold of 0.70. Also, the composite reliability varies from 0.545 to 0.712 which is above the preferred value of 0.50 and this proves that the second part is internally consistent.

Table (3): reliability of the questions involved in the second part by using Cronbach's Alpha coefficient

Constructs	***Number of Statements***	***Cronbach's Alpha***	***Composite Reliability***
Potential Benefits of AI Technologies in Port Supply Chains	4	0.878	0.655
Optimization of Port Performance	4	0.716	0.616
Effect of AI Technologies on Various Stakeholders	4	0.979	0.712
Optimization of Supply Chain Management Processes within Ports	4	0.760	0.545

Descriptive Statistics of Constructs

In this subsection, the researcher provides detailed descriptive statistics and analyses for each construct. The descriptive analysis is comprised of the following: Minimum, Maximum, Mean, and Standard Deviation.

- The average of the first construct is around 0.5 which means that the respondents see that using AI technologies in port supply chains provide potential benefits as improved efficiency and reduced costs.

- The average of the second construct is around 0.5 which means that the respondents see that using AI technologies improve the accuracy and reliability of supply chain data which is critical for optimizing port performance.

- The average of the third construct is around 0.5 which means that the respondents see that using AI technologies in port supply chains affect various stakeholders, such as shippers, carriers, terminal operators, and regulators.

- The average of the fourth construct is around 0.5 which means that the respondents see that using AI technologies help

optimizing supply chain management processes within ports, such as cargo handling, inventory management, and scheduling.

Table (4): descriptive statistics for the second part constructs (n=510)

variable	***Minimum***	***Maximum***	***Mean***	***Standard Deviation***
Potential Benefits of AI Technologies in Port Supply Chains	0.25	1	0.5245	0.20345
Optimization of Port Performance	0.25	1	0.5069	0.18858
Effect of AI Technologies on Various Stakeholders	0.25	0.75	0.4838	0.18371
Optimization of Supply Chain Management Processes within Ports	0	1	0.5887	0.24994

Part 3: Key Challenges & Opportunities with Application of AI Technologies in Port Supply Chain

Descriptive Statistics

This subsection will tackle the descriptive statistics of the questions involved in the third part of the questionnaire through presenting the frequency and percentage of each selected answer.

Table (5): description of the questions involved in the third part (n=510)

Variable	*Frequency*	*Percentage*
Key Challenges due to Implementing AI Technologies		
data quality	327	64.1%
integration with existing systems	17	3.3%
cybersecurity	159	31.2%
skill gap	16	3.1%
Management of Challenges and Potential Risks		
workforce adaption and skills development	397	77.8%
ethical considerations	439	86.1%
collaboration between stakeholders	52	10.2%
regulatory environment	172	33.7%
Alignment of AI Technologies with Business Goals and Strategic Objectives		
scale and complexity of PSC	301	59%
availability of data	268	52.5%
type of operations	433	84.9%
competitive landscape	76	14.9%

The sum of the percentages is not equal to 100% as these questions allow multiple choices.

Creating Indicators

In the third part, 3 indicators will be created. These created indicators are presented in the row form of Table (5).

Reliability Analysis

Cronbach's Alpha reflects a good reliability of the research questions as its values range from 0.752 to 0.984 for the constructs which exceeded the threshold of 0.70. Also, the composite reliability varies from 0.542 to 0.740 which is above the preferred value of 0.50 and this proves that the second part is internally consistent.

Table (6): reliability of the questions involved in the second part by using Cronbach's Alpha coefficient

Constructs	***Number of Statements***	***Cronbach's Alpha***	***Composite Reliability***
Key Challenges due to Implementing AI Technologies	4	0.984	0.740
Management of Challenges and Potential Risks	4	0.752	0.542
Alignment of AI Technologies with Business Goals and Strategic Objectives	4	0.785	0.621

Descriptive Statistics of Constructs

In this subsection, the researcher provides detailed descriptive statistics and analyses for each construct. The descriptive analysis is comprised of the following: Minimum, Maximum, Mean, and Standard Deviation. It's clear that:

- The average of the first construct is around 0.25 which means that the respondents see that there are few key challenges associated with implementing AI technologies in supply chain and port operations.

- The average of the second construct is around 0.5 which means that the respondents see that organizations can effectively manage the challenges and mitigate potential risks associated with AI implementation in supply chain and port operations.

- The average of the third construct is around 0.5 which means that the respondents see that organizations can ensure that the AI technologies they implement are aligned with their business goals and strategic objectives for supply chain and port operations.

Table (7): descriptive statistics for the third part constructs (n=510)

Variable	***Minimum***	***Maximum***	***Mean***	***Standard Deviation***
Key Challenges due to Implementing AI Technologies	0.25	0.5	0.2544	0.03295
Management of Challenges and Potential Risks	0.25	0.75	0.5196	0.18034
Alignment of AI Technologies with Business Goals and Strategic Objectives	0.25	0.75	0.5284	0.18522

Part 4: Main AI Technologies

Descriptive Statistics

This subsection will tackle the descriptive statistics of the questions involved in the fourth part of the questionnaire through presenting the frequency and percentage of each selected answer.

Table (8): description of the questions involved in the fourth part (n=510)

Variable	*Frequency*	*Percentage*
Specific AI Technologies to Improve Supply Chain Management		
machine learning	384	75.3%
natural language processing	175	34.3%
computer vision	256	50.2%
robotics	262	51.4%
Optimization of Flow of Goods through Egypt's Ports		
predictive maintenance	349	68.4%
real-time tracking and monitoring	117	22.9%
route optimization	413	81%
automated inspection and quality control	140	27.5%
Integration of AI with Other Technologies		
supply chain transparency and traceability	102	20%
smart contracts	285	55.9%
predictive maintenance	382	74.9%
autonomous vehicles	291	57.1%

The sum of the percentages is not equal to 100% as these questions allow multiple choices.

Creating Indicators

In the fourth part, 3 indicators will be created. These created indicators are presented in the row form of Table (8).

Reliability Analysis

Cronbach's Alpha reflects a good reliability of the research questions as its values range from 0.775 to 0.825 for the constructs which exceeded the threshold of 0.70. Also, the composite reliability varies from 0.542 to 0.645 which is above the preferred value of 0.50 and this proves that the second part is internally consistent.

Table (9): reliability of the questions involved in the second part by using Cronbach's Alpha coefficient

Constructs	Number of Statements	Cronbach's Alpha	Composite Reliability
Specific AI Technologies to Improve Supply Chain Management	4	0.775	0.572
Optimization of Flow of Goods through Egypt's Ports	4	0.825	0.542
Integration of AI with Other Technologies	4	0.790	0.645

Descriptive Statistics of Constructs

In this subsection, the researcher provides detailed descriptive statistics and analyses for each construct. The descriptive analysis is comprised of the following: Minimum, Maximum, Mean, and Standard Deviation.

It's clear that:

The average of the first construct is around 0.5 which means that the respondents see that there are specific AI technologies that are currently used to improve supply chain management in ports around world.

The average of the second construct is around 0.5 which means that the respondents see that AI technologies can be used to optimize the flow of goods through Egypt's ports from the arrival of cargo ships to the final delivery of goods to their intended recipients.

The average of the third construct is around 0.5 which means that the respondents see that AI technologies can be integrated with other technologies such as block chain and the IoT to create a more robust and effective supply chain management system in Egypt's ports.

Table (10): descriptive statistics for the fourth part constructs (n=510)

	Minimum	***Maximum***	***Mean***	***Standard Deviation***
Specific AI Technologies to Improve Supply Chain Management	0	1	0.5279	0.21101
Optimization of Flow of Goods through Egypt's Ports	0.25	0.75	0.4995	0.17833
Integration of AI with Other Technologies	0.25	0.75	0.5196	0.19092

Correlation Analysis

Table (11): Pearson's Correlation Coefficients

	Potential Benefits of AI Technologies in Port Supply Chains	Optimization of Port Performance	Effect of AI Technologies on Various Stakeholders	Optimization of Supply Chain Management Processes within Ports	Key Challenges due to Implementing AI Technologies	Management of Challenges and Potential Risks	Alignment of AI Technologies with Business Goals and Strategic Objectives	Specific AI Technologies to Improve Supply Chain Management	Optimization of Flow of Goods through Egypt's Ports	Integration of AI with Other Technologies
Potential Benefits of AI Technologies in Port Supply Chains	1									
Optimization of Port Performance	0.591**	1								
Effect of AI Technologies on Various Stakeholders	0.704**	0.606**	1							
Optimization of Supply Chain Management Processes within Ports	0.645**	0.680**	0.724**	1						
Key Challenges due to Implementing AI Technologies	0.710**	0.671**	0.762**	0.731**	1					
Management of Challenges and Potential Risks	0.657**	0.679**	0.727**	0.739**	0.767**	1				
Alignment of AI Technologies with Business Goals and Strategic Objectives	0.626**	0.658**	0.688**	0.715**	0.703**	0.790**	1			
Specific AI Technologies to Improve Supply Chain Management	-0.181**	-0.183**	-0.171**	-0.182**	-0.177**	-0.188**	-0.189**	1		
Optimization of Flow of Goods through Egypt's Ports	0.583**	0.696**	0.699**	0.694**	0.744**	0.806**	0.798**	-0.201**	1	
Integration of AI with Other Technologies	0.591**	0.620**	0.537**	0.598**	0.696**	0.785**	0.717**	-0.202**	0.821**	1

Comparing Means

There are many cases in statistics where we are interested in comparing means for two populations or samples. This technique is often used in hypothesis testing to determine whether a process or treatment influences the population of interest, or whether two groups are different from one another. The suitable technique is chosen depending on the type of data and how that data is grouped together. If there are 2 groups independent-sample T-test is used, while in case of more than 2 groups ANOVA test is the accurate test.

Gender

Table (12): each construct in relationship with the gender of the respondents

Characteristic **Construct**	Gender		P-Value
	female	male	
Potential Benefits of AI Technologies in Port Supply Chains	0.4239	0.5467	0.000
Optimization of Port Performance	0.3587	0.5395	0.000
Effect of AI Technologies on Various Stakeholders	0.3804	0.5066	0.000
Optimization of Supply Chain Management Processes within Ports	0.3804	0.6346	0.000
Key Challenges due to Implementing AI Technologies	0.3804	0.5604	0.000
Management of Challenges and Potential Risks	0.4022	0.5209	0.000
Alignment of AI Technologies with Business Goals and Strategic Objectives	0.3804	0.5502	0.000
Specific AI Technologies to Improve Supply Chain Management	0.2745	0.25	0.000
Optimization of Flow of Goods through Egypt's Ports	0.4239	0.5407	0.000
Integration of AI with Other Technologies	0.4239	0.5514	0.000

The previous table illustrates that there are significant relationships between the gender of the respondents and their opinion toward all the constructs with 95% confidence. Furthermore, males support each construct more than females except for the existence of specific AI technologies to improve supply chain management as we can see that females are support this construct more than males.

Age Group

Table (13): each construct in relationship with the age of the respondents

Characteristic **Construct**	Age Group				P-Value
	under 30 years old	from 30 to 40 years old	from 41 to 50 years old	more than 50 years old	
Potential Benefits of AI Technologies in Port Supply Chains	0.5183	0.4022	0.5685	0.625	0.000
Optimization of Port Performance	0.5183	0.3569	0.5373	0.6707	0.000
Effect of AI Technologies on Various Stakeholders	0.4939	0.3859	0.5192	0.5488	0.000
Optimization of Supply Chain Management Processes within Ports	0.5915	0.4022	0.6394	0.7713	0.000

Key Challenges due to Implementing AI Technologies	0.5427	0.3859	0.5685	0.6494	0.000
Management of Challenges and Potential Risks	0.4451	0.4149	0.5288	0.622	0.000
Alignment of AI Technologies with Business Goals and Strategic Objectives	0.5427	0.4004	0.5288	0.6738	0.000
Specific AI Technologies to Improve Supply Chain Management	0.25	0.2663	0.25	0.25	0.000
Optimization of Flow of Goods through Egypt's Ports	0.5183	0.4167	0.5385	0.6463	0.000
Integration of AI with Other Technologies	0.5183	0.4475	0.5589	0.5976	0.000

The previous table illustrates that there are significant relationships between the age group of the respondents and their opinion toward all the constructs with 95% confidence. Furthermore, the respondents who aged more than 50 years old support each construct more than the respondents in the other age groups followed by those who aged from 41 to 50 years old.

Educational Level

Table (14): each construct in relationship with the educational level of the respondents

Characteristic Construct	Educational Level				P-Value
	higher diploma	bachelor's degree	master's degree	PhD degree	
Potential Benefits of AI Technologies in Port Supply Chains	0.3714	0.5615	0.5217	0.4318	0.000
Optimization of Port Performance	0.3714	0.5339	0.4973	0.4621	0.000
Effect of AI Technologies on Various Stakeholders	0.25	0.5032	0.5217	0.4621	0.000
Optimization of Supply Chain Management Processes within Ports	0.3143	0.6144	0.6304	0.553	0.000
Key Challenges due to Implementing AI Technologies	0.3714	0.541	0.5897	0.4621	0.000
Management of Challenges and Potential Risks	0.3143	0.5158	0.5408	0.4621	0.000
Alignment of AI Technologies with Business Goals and Strategic Objectives	0.3143	0.5607	0.5625	0.3712	0.000
Specific AI Technologies to Improve Supply Chain Management	0.3143	0.25	0.25	0.25	0.000
Optimization of Flow of Goods through Egypt's Ports	0.3714	0.5418	0.5625	0.4318	0.000
Integration of AI with Other Technologies	0.4357	0.5426	0.5625	0.4621	0.000

The previous table illustrates that there are significant relationships between the educational level of the respondents and their opinion toward all the constructs with 95% confidence. Furthermore, the respondents who pursued a master's degree support each construct more than the respondents who pursued other degrees followed by those who pursued a bachelor's degree.

Administrative Position

Table (15): each construct in relationship with the administrative position of the respondents

Characteristic Construct	Administrative Position					P-Value
	director of department	unit director	head of department	consultant	any other position	
Potential Benefits of AI Technologies in Port Supply Chains	0.6556	0.4964	0.528	0.5982	0.25	0.000
Optimization of Port Performance	0.5639	0.525	0.5262	0.5446	0.25	0.000
Effect of AI Technologies on Various Stakeholders	0.5417	0.4661	0.5157	0.5446	0.25	0.000
Optimization of Supply Chain Management Processes within Ports	0.6556	0.5982	0.542	0.7946	0.25	0.000
Key Challenges due to Implementing AI Technologies	0.6111	0.525	0.5577	0.5952	0.2075	0.000
Management of Challenges and Potential Risks	0.5417	0.4821	0.5122	0.619	0.25	0.000
Alignment of AI Technologies with Business Goals and Strategic Objectives	0.5639	0.5393	0.542	0.5714	0.25	0.000
Specific AI Technologies to Improve Supply Chain Management	0.275	0.25	0.25	0.25	0.25	0.000
Optimization of Flow of Goods through Egypt's Ports	0.5861	0.5411	0.5122	0.5952	0.25	0.000
Integration of AI with Other Technologies	0.5667	0.5571	0.5402	0.5952	0.25	0.000

The previous table illustrates that there are significant relationships between the administrative position of the

respondents and their opinion toward all the constructs with 95% confidence. Furthermore, the respondents who work as directors of a department support the highlighted constructs more than the respondents who work in other administrative positions, while those who work as consultants support the other constructs more than the respondents which work in other administrative positions.

Work Experience

Table (16): each construct in relationship with the work experience of the respondents

Characteristic / **Construct**	Work Experience				P-Value
	less than 5 years	from 5 to 10 years	from 11 to 20 years	over 20 years	
Potential Benefits of AI Technologies in Port Supply Chains	0.3705	0.4752	0.515	0.6296	0.000
Optimization of Port Performance	0.4187	0.4566	0.4979	0.5833	0.000
Effect of AI Technologies on Various Stakeholders	0.3464	0.4566	0.5171	0.541	0.000
Optimization of Supply Chain Management Processes within Ports	0.4428	0.4917	0.6068	0.7037	0.000
Key Challenges due to Implementing AI Technologies	0.4187	0.4566	0.5684	0.5966	0.000
Management of Challenges and Potential Risks	0.3464	0.4401	0.5855	0.5516	0.000
Alignment of AI Technologies with Business Goals and Strategic Objectives	0.3705	0.4897	0.5513	0.5847	0.000
Specific AI Technologies to Improve Supply Chain Management	0.2771	0.25	0.25	0.25	0.000
Optimization of Flow of Goods through Egypt's Ports	0.3946	0.4752	0.5342	0.5939	0.000
Integration of AI with Other Technologies	0.4187	0.4938	0.5684	0.5741	0.000

The previous table illustrates that there are significant relationships between the work experience of the respondents and their opinion toward all the constructs with 95% confidence. Furthermore, the respondents who have over 20 years of experience support each construct more than the respondents who have other years of experience except for the management of challenges and potential risks as we can see the

respondents who have from 11 to 20 years of experience support this construct more than the others.

Affiliation of Institution

Table (17): each construct in relationship with the gender of the respondents

Characteristic Construct	Affiliation of Institution		P-Value
	governmental public sector	private sector eligibility	
Potential Benefits of AI Technologies in Port Supply Chains	0.5756	0.4873	0.000
Optimization of Port Performance	0.5733	0.4585	0.000
Effect of AI Technologies on Various Stakeholders	0.4884	0.4805	0.000
Optimization of Supply Chain Management Processes within Ports	0.6512	0.5432	0.000
Key Challenges due to Implementing AI Technologies	0.5465	0.5144	0.000
Management of Challenges and Potential Risks	0.5465	0.4653	0.000
Alignment of AI Technologies with Business Goals and Strategic Objectives	0.5384	0.5059	0.000
Specific AI Technologies to Improve Supply Chain Management	0.2605	0.25	0.000
Optimization of Flow of Goods through Egypt's Ports	0.5651	0.4864	0.000
Integration of AI with Other Technologies	0.5663	0.5008	0.000

The previous table illustrates that there are significant relationships between the gender of the respondents and their opinion toward all the constructs with 95% confidence. Furthermore, the respondents who work in governmental public sector institutions support each construct more than those who work in private sector institutions.

Secondly, AI techniques are used as another method of analysis the results of data using machine learning method such as regression trees according to each demographic variable. It is a method for classification of data set into smaller groups and then fit a simple model (constant) for each subgroup. Unfortunately, a single tree model tends to be highly unstable and a poor predictor. However, by bootstrap aggregating

(bagging) regression trees, this technique can become quite powerful and effective. Moreover, this provides the fundamental basis of more complex tree-based models such as random forests and gradient boosting machines as shown in figure (1).

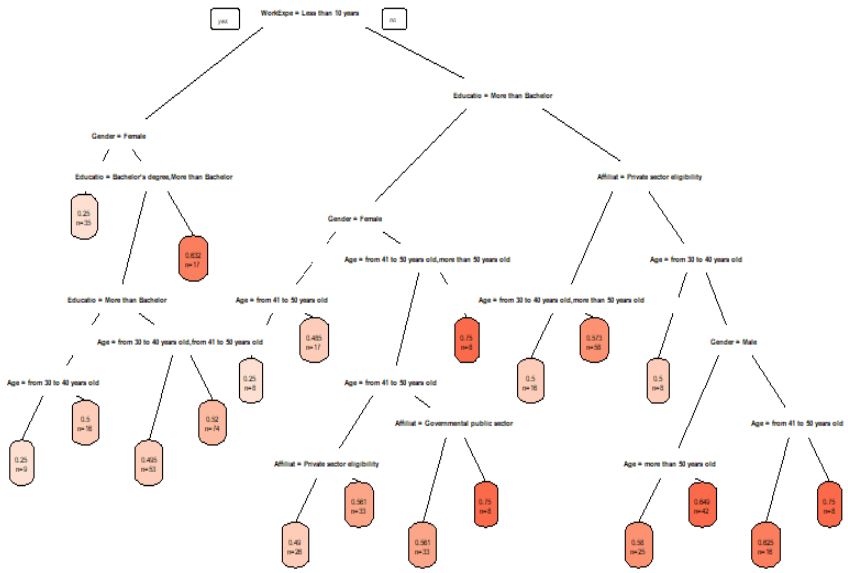

figure (1)

Regression trees analyzed the potential benefits of AI Technologies in ports supply chain in details according to education, gender and work of experience as follow:

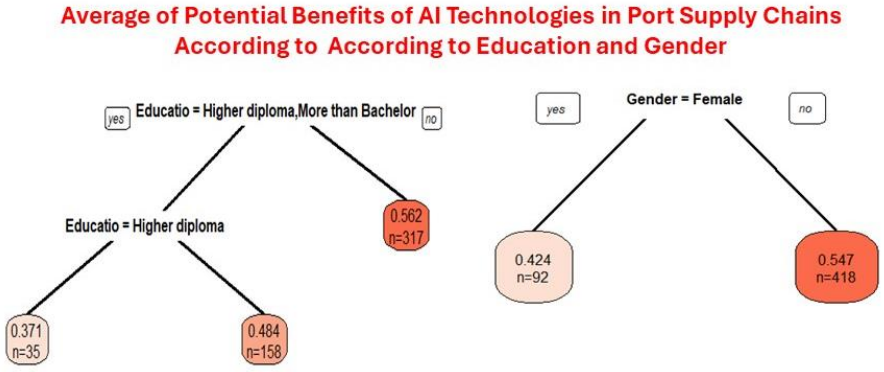

figure (2)

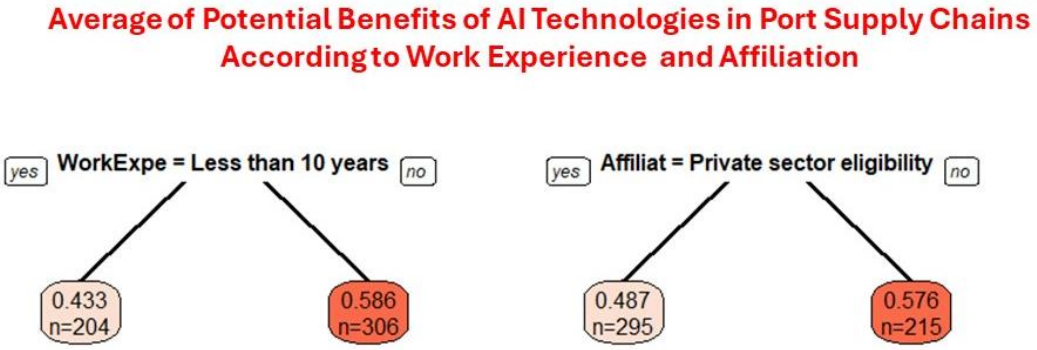

figure (3)

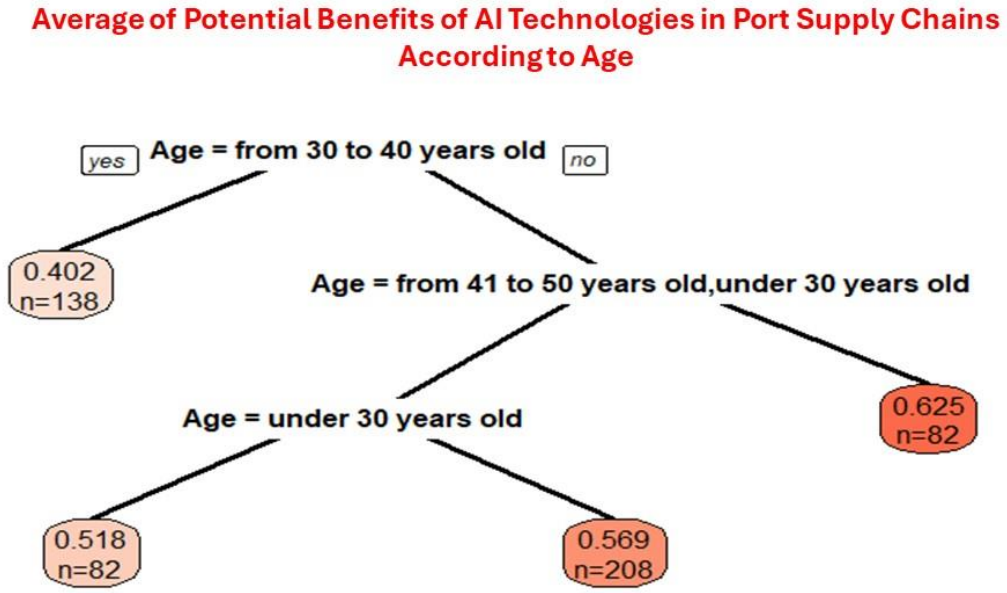

figure (4)

Conclusion and Recommendations

This study suggests that the integration of AI in SCM contributes improvement of port performance in Egypt, based on the results of the questionnaires. However, its remains insufficient as it faces several obstacles, including the variability of AI maturity among supply chain actors, data security concerns, and the need to develop specialised skills in AI. Specifically, the findings of the study were analysed in relation to the existing literature and their relevance to the research objectives and questions.

Summary of the Key Findings of the Research

After carrying out a comprehensive quantitative analysis, this study puts forward several compelling arguments in favour of the application of AI and the urgent need to integrate it into the supply chain in order to improve the performance of Egyptian ports.

The main findings are summarized as follows:

In terms of the stated reasoning for implementing AI in Egypt, a study of important theories and a small number of real-world studies justify adding AI into supply chain management. Procurement should increase port performance and ensure its sustainability. Furthermore, artificial intelligence should enhance interactions among various stakeholders, eliminate time waste, raise corporate productivity and efficiency, and cut costs.

This study used questionnaires and regression tree to reach critical conclusions, demonstrating the need of considering both economic benefits and ethical concerns while incorporating AI into Egyptian port operations and supply chain.

These findings emphasize the need of enacting robust legislation while promoting concepts like transparency, inclusivity, and sustainability. Furthermore, for this integration to be successful and long-lasting, the economic benefits must be distributed fairly. In Egypt, the use of AI brings up significant economic opportunities by improving operational efficiency, supply chain management, and port sector competitiveness.

The questionnaire results revealed the importance of Artificial Intelligence (AI) in enhancing the efficiency, sustainability, and

competitiveness of Egyptian port operations, as well as highlighting complex concerns that must be properly addressed. This supports a fair distribution of economic benefits from AI across supply chain actors and port operators. A balanced and ethical strategy is thus essential to maximize port performance while simultaneously addressing social and environmental issues.

In this regard, it is critical to establish a solid regulatory framework that oversees the use of AI, thereby supporting openness, inclusion, and sustainability. Staff training and skill development are also recommended to ensure a smooth transition to increasingly automated procedures. It is also vital to create regular evaluation and monitoring systems to examine AI's influence on society, the environment, and economics. Finally, encouraging collaboration among supply chain actors and port operators can lead to creative approaches to maximize AI's economic benefits while also addressing social and environmental problems.

According to the study's questionnaire findings, Egypt needs implement new strategies aimed at integrating AI into port operations and improving performance in order to become a major commercial and financial center in the MENA region. Given its strategic geographical location, this would serve to open up new avenues for international cooperation, notably in the financial sector, not just in Afro-Arab collaboration but also in Afro-European cooperation, particularly in the Mediterranean. To achieve this, Egypt must establish a strong regulatory framework that governs the use of AI, thereby promoting transparency, inclusion, and sustainability, as well as a strong and sustainable technological infrastructure that will allow it to successfully integrate with other African countries.

Limitations

Just like any other research, this study has its own limitations, which are mainly related to the research scope, sample, and data collection technique. Although these limitations have limited the research's scope, they have opened a new avenue for further exploration. Accordingly, the researcher brings forth some recommendations for future studies that the researcher sees as under-covered, or this research opens a gate for them to be performed.

The first limitation is related. to the sample, which only covers seaport sector in Egypt. The researcher did not examine the impact of applying AI across different sectors, such as logistics and manufacturing companies especially those companies which heavily depend on SCM. Accordingly, it is recommended to expand the current research to cover these sectors in future studies. This will provide a deeper understanding of the impact of integrating AI into SCM and understand how AI application would differ across sectors. Moreover, it will provide valuable insights for academics and practitioners to follow, and it will increase the validity and generalizability of the research.

The second limitation is related to the geographic location of the investigation, as this study is only focused on Egypt. Although Egypt is a developing country that has faced several socio-economic transformations and historical events, it has raised the importance of integrating AI into SCM and addressing its effect on port performance. Nevertheless, the conclusions drawn from this study can only be generalized to other countries with similar conditions to those of Egypt. This is because the unique economic conditions related to

developing countries can lead to different results. Therefore, to better understand the effect of AI and SCM on port performance across countries, it is recommended that the current research to be expanded to different countries. This will contribute to a better understanding of the specificities of each country, the unique barriers to AI adoption, and the specific benefits in terms of port efficiency, sustainability, and competitiveness. Ultimately, considering a variety of national contexts would help to broaden the scope of this research in this area.

The third limitation is related to the data gathering and analysis techniques. The researcher depends on primary data collection using questionnaires. Nevertheless, the researcher did not collect data using different sources, such as interviews, to verify the results obtained from the questionnaires. This shows that the analysis was based on quantitative measurements and did not include qualitative measurements. Although collecting primary data from participants in this sector provides valuable information, it has inherent limitations. Accordingly, the quality of the results depends on the accuracy and reliability of the respondents. This suggests other areas for research by verifying the results through interviews and quantitative measures

Recommendations of the Study

Based on the above-mentioned findings, the researcher provided recommendations that can help the policymakers of seaports operating in Egypt improve their companies' efficiency by adapting and improving the usage of AI in their activities. Firstly, the government of Egypt should set a clear strategy for AI usage. This strategy needs to highlight the objectives and resources needed to promote the usage of AI in port operations while taking into account ethical and environmental standards.

Secondly, it is important to ensure that the workforce has the necessary skills to benefit from AI usage. Accordingly, it is recommended to provide training programs in order to train those workers on how to use and adopt AI and other related technologies in their work.

Finally, emphasis the academics and research and development departments to begin developing their AI agenda. This can be done by providing incentives to companies and universities that want to research and develop AI for ports.

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