Causal Factors Affecting the Role of Artificial Intelligence (AI) in Enhancing the Efficiency of Green Logistics

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Abstract

This research aims to: 1) To analyze the impact of technological, human resource, and economic factors on the adoption of AI in logistics systems. 2) To assess the role of policy and legal factors and the efficiency of green logistics systems by considering key indicators. to test cause-and-effect relationships. Data were collected using questionnaires distributed to 360 logistics managers and officers in organizations that have implemented AI. Structural Equation Modeling (SEM) was employed for hypothesis testing. The research findings indicate that: 1) Technological factors positively influence the role of AI in enhancing the efficiency of green logistics. 2) Human resource factors positively affect the application of AI in green logistics. 3) Policy and legal factors significantly influence the adoption of AI in sustainable logistics systems. 4) Economic factors affect the capability to apply AI to improve environmental logistics efficiency. The findings of this research can serve as a guideline for industrial sector operations and related agencies. The insights can be applied to businesses with similar characteristics and operating environments, including strategic planning in the logistics industry, policy and regulation design, technology and innovation development, sustainable resource management, and support for skills development and employment to enhance operational efficiency and effectiveness.

Keywords: AI, efficiency, green logistics

1. Introduction

In the present era, the development of Artificial Intelligence (AI) technology has played an important role in various business and industrial sectors, especially in logistics, which is a system related to supply chain management, movement of goods, and services that require speed and accuracy. However, the challenge in current logistics operations is to reduce the impact on the environment, which has led to the concept of green logistics, which focuses on reducing greenhouse gas emissions and efficient use of resources (Bai & Sarkis, 2021). The increase in international economic activities and trade has led to a continuous increase in the transportation of goods. The United Nations (UNCTAD, 2022) stated that more than 80% of international trade relies on maritime transport, which contributes to 940 million tons of greenhouse gas emissions per year. The use of AI in logistics can reduce this impact by improving the efficiency of transportation routes and reducing energy consumption through accurate demand forecasting (Wang et al., 2020). Although many studies have focused on the application of AI in logistics management, there is still a lack of comprehensive studies on the causal factors affecting the success of AI implementation in green logistics in a deeper dimension. Variables such as technological infrastructure, personnel capabilities, and government policies There has not been a systematic analysis to find a clear relationship (Singh & Sahu, 2022).

This study aims to fill this gap through in-depth analysis and comprehensive empirical data collection. This research is expected to provide useful results in both theoretical and practical aspects. In theory, it will help develop new knowledge on the role of AI in enhancing the efficiency of green logistics, including identifying key causal factors that influence the success of AI implementation. In practice, business organizations can use the research findings to plan effective strategies and policies to increase sustainability and reduce environmental impacts, which will help achieve the Sustainable Development Goals (SDGs) set by the United Nations (UN, 2022). According to a report by McKinsey & Company (2021), organizations that use AI in supply chain management can increase operational efficiency by 15-20% and reduce greenhouse gas emissions by more than 10% in the long run. In addition, a report by the International Transport Forum (2022) indicated that the implementation of AI in logistics can reduce transportation costs by up to 30%, clearly demonstrating the high potential of this technology to create a positive impact on the economy and the environment. In management, it is a guideline for managing innovation and technological advancements. Businesses need to adapt and respond to changes in the environment in order for the business to survive, grow steadily, and be competitive in the international market, which leads to good results for the organization in the future (Pimonratanakan, 2022).

1.1 Research Objective

1. To analyze the impact of technological, human resource, and economic factors on the adoption of AI in logistics systems.

2. To assess the role of policy and legal factors and the efficiency of green logistics systems by considering key indicators.

1.2 Research hypothesis

Hypothesis 1: Objective technological factors have a positive effect on the role of AI in enhancing the efficiency of green logistics.

Hypothesis 2: Human resource factors have a positive effect on the application of AI in green logistics.

Hypothesis 3: Policy and legal factors affect the use of AI in sustainable logistics systems.

Hypothesis 4: Economic factors affect the ability to apply AI to enhance the efficiency of environmental logistics.

1.3 Related theoretical concepts

1. Basic concepts of artificial intelligence (AI) and green logistics

Artificial intelligence refers to computer systems that can imitate the functioning of the human brain through automatic learning, analysis, and decision-making (Russell & Norvig, 2021). This technology ranges from machine learning and natural language processing to intelligent robotic systems, which can be used to improve the efficiency of a variety of business processes. In the context of logistics, AI plays an important role in supply chain management, especially in product demand forecasting, warehouse management, and optimal transportation routes. For example, AI is used to predict demand in advance to prevent product shortages and reduce unnecessary inventory (Wang et al., 2020). Green logistics refers to logistics processes that take into account environmental impacts, focusing on reducing greenhouse gas emissions, efficient energy use, and reducing waste from logistics processes (Bai & Sarkis, 2021). This approach supports sustainable development in line with the goals of the United Nations (UN, 2022).

2. Supply chain management theory

Supply chain management theory focuses on planning, controlling, and coordinating all activities related to the efficient sourcing, production, and distribution of goods to customers and reducing costs. It covers everything from suppliers and manufacturers to consumers (Chopra & Meindl, 2021). The company executives have to implement Smart Logistics as soon as possible so that results are achievable in company (Setthachotsombut, 2024). This concept focuses on increasing efficiency and reducing costs throughout the supply chain, taking into account quality factors, response time, and the sustainability of the system. Key indicators in supply chain management include operating costs, delivery times, customer satisfaction, and reduced production waste (Christopher, 2016). In the context of green logistics, this theory emphasizes the importance of management that reduces environmental impacts, such as selecting environmentally friendly sources of raw materials, reducing transportation distances, and optimizing resource use through data analysis with AI technology (Bai & Sarkis, 2021). AI-integrated supply chain management enhances predictive capabilities and rapid response, resulting in systematic, accurate, and resource-saving decisions (Wang et al., 2020).

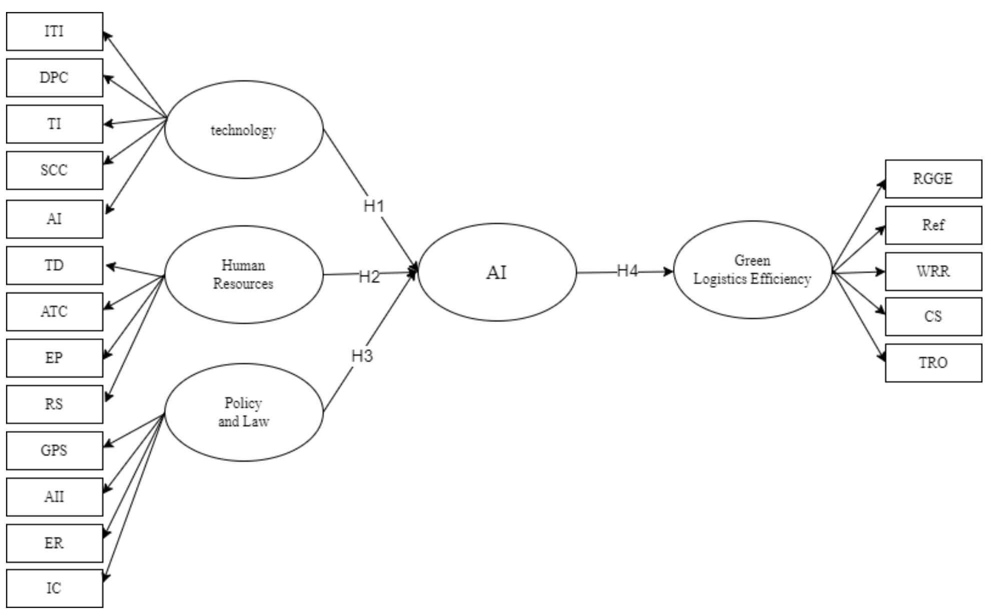
3. Systems Theory

Systems theory is a conceptual framework that focuses on understanding and analyzing systems with diverse components that are interconnected and interact with each other (von Bertalanffy, 1968). It views any system as consisting of multiple subcomponents that work together to achieve the overall objectives of that system. This concept is suitable for studying complex logistics processes, which involve networks of manufacturers, distributors, and consumers who need to coordinate systematically. In the context of green logistics and AI, the application of systems theory enables the efficient design and management of complex logistics processes. For example, AI-based transportation route planning takes into account factors such as distance, transport volume, and greenhouse gas emissions. AI systems can perform in-depth data analysis and propose the most suitable alternatives to reduce environmental impacts (McKinsey & Company, 2021). The application of systems theory also supports a strategic overview of the supply chain, enabling the identification of areas for improvement and optimization of key areas, emphasizing the relationships between different parts to increase business capabilities and reduce resource waste (Christopher, 2016).

4. Automatic Decision Theory

Automatic decision theory is a conceptual framework that emphasizes the decision-making of systems or machines that use data and algorithms to process information to reduce complexity and increase decision accuracy (Simon, 1997). This concept is particularly important in the context of AI, which can learn and analyze data to support automated decision-making, especially in logistics related to routing, inventory management, and resource allocation. In green logistics, AI using this framework can reduce the time spent analyzing data and suggesting appropriate alternatives to increase efficiency and reduce environmental impact. For example, AI is used to analyze carbon emissions and plan safe and environmentally friendly transportation routes (Wang et al., 2020). In addition, the theory supports the reduction of errors caused by human decision-making, as AI can process data from multiple sources simultaneously and accurately predict outcomes, which is suitable for highly complex systems such as global supply chains (McKinsey & Company, 2021).

Research Conceptual Framework



2. Methodology

2.1 Population and Sample

The population used in this study is logistics managers and staff in organizations that apply AI to improve efficiency in the logistics system. The unit of analysis for this research is the organization system.

The sample group used in quantitative research is logistics managers and staff. The criteria used to determine the sample is 10-20 times per 1 observed variable (Hair, 2010). This research has 18 observed variables, resulting in a sample of 360 people from leading logistics companies and companies that use AI in supply chain management. To increase the reliability of the research results, the research uses a sample of 360 people, resulting in an appropriate sample size according to the concept of Hair et al. (Hair et al., 2010).

2.2 Research Instruments

The instruments used to collect data The researcher used a questionnaire, which is a closed-ended question, divided into 6 parts, where part 1 is a multiple-choice question, and parts 2-6 are Likert-type (1967) rating scales, and part 7 is an open-ended question. Part 1 is general information about the business. Multiple-choice questions Part 2 is an opinion on the use of AI in technology. Part 3 is an opinion on the use of AI in human resources. Part 4 is an opinion on the use of AI in policy and law. Part 5 is an opinion on the use of AI in economics. Part 6 is the efficiency results of green logistics. Part 7 is additional suggestions.

2.3 Quality control of the research instrument

The steps are: 1) Content validity testing by giving the created questionnaire to 3 experts in logistics and AI management to check the consistency of the questions with the objectives, the conceptual framework of the research, and definitions of specific terms of the variables used in the research. The questions were improved. The index of consistency between the questions and the characteristics according to the research objectives was found to be no less than 0.74 according to the recommendations of Hair et al. (2010). It can be used as a question. 2) Validation of the instrument To test the validity of the instrument from the experiment by trying it out with a group of 30 managers and logistics officers in organizations that have applied AI, who are not real samples, using the alpha coefficient analysis according to Cronbach's method (Cronbach, 1984). The reliability of the entire questionnaire must be at least 0.70 to be considered acceptable (Hair et al., 2010). From the test, it was found that the reliability of the entire questionnaire was equal to 0.80. And from the results of testing the quality of the research instrument by checking the reliability using the alpha coefficient according to Cronbach's method, it was found that the reliability of the questionnaire divided by aspects was between 0.810 and 0.901, which met the requirements. Therefore, the questionnaire can be used to collect research data.

2.4 Statistics and data analysis

1. The researcher analyzed the obtained data using descriptive statistics and analyzed the obtained data to find statistical values, including frequency, percentage, and standard deviation, using a ready-made statistical program and structural equation analysis.

2. Analysis of causal factors using path analysis using a ready-made statistical program and structural equation analysis, and considering the /df value to be less than 2, the CFI index value approaching 1, the RMSEA index value, and the RMR index value to be less than 0.05, which is in the acceptable range, which is considered that the model is consistent with the empirical data (Hair et al., 2010).

3. Results

The respondents in this research were managers and logistics officers in organizations that applied AI, totaling 360 people. The results of the study of the general information of the respondents found that most of them were women. accounting for 59.28 percent, most of them were between 41-45 years old, the most accounting for 30.75 percent, the most of them had a bachelor's degree, the most accounting for 62.33 percent, the most of them had 11-15 years of work experience, the most accounting for 42.38 percent, the most of them were logistics officers, the most accounting for 72.02 percent, the most of them had less than 50 personnel, the most accounting for 76.18 percent, the most of them had been in business for 5-10 years, the most accounting for 49.58 percent, and the most of them had the nature of the transportation business, the most accounting for 45.15 percent, as shown in Table 1.

Table 1 :. General data study results

General information	amount	percentage
Gender		
Male	146	40.72
Female	214	59.28
Age		
Less than 31 years	86	23.82
31 - 35 years	53	14.68
36 - 40 years	30	8.31
41-45 years	110	30.75
More than 45 years	81	22.44
Educational level		
Less than a bachelor's degree	54	14.96
Bachelor's degree	224	62.33
More than a bachelor's degree	82	22.71
Work experience		
Less than 6 years	22	6.09
6-10 years	100	27.70
11-15 years	152	42.38
More than 15 years	86	23.82
Current position		
Manager	100	27.98
Logistics officer	260	72.02
Number of personnel		
Less than 50 people	274	76.18
50-100 people	86	23.82
Duration of business		
Less than 5 years	59	16.34
5-10 years	178	49.58
11-15 years	72	19.94
More than 15 years	51	14.13
Type of business		
Transportation	162	45.15
Storage	105	29.09
Supply chain operations	93	25.76
Total	**360**	**100.00**

There is a sample group that responded to the questionnaire that has a high level of overall opinion, and in each of the 5 aspects, namely technology, human resources, policy and law, economics, and the results of green logistics efficiency, it is at a high level, as shown in Table 2.

Table 2 :. Results of the study of overall opinions

Order No.	list	$\bar{X}$	SD	Opinion level
1	Technology	4.36	0.29	Good
2	Human Resources	4.27	0.38	Good
3	Policy and Law	4.35	0.45	Good
4	Economic	4.17	0.36	Good
5	Green Logistics Performance Results	4.03	0.36	Good
	Total	**4.24**	**0.37**	Good

The researcher used the multivariate statistical analysis method using path analysis to test the research hypothesis to check according to the preliminary agreement of the structural equation analysis. From the test, it was found that the correlation coefficients of all 18 observed variables, 153 pairs, were related, and the relationship of all pairs of variables had the same direction, with the correlation coefficients between the variables being a positive relationship. The coefficient value is between 0.181 and 0.892, which is statistically significant at the 0.01 level, where the correlation coefficient of the variables must not exceed 0.90, indicating that the studied variables do not have problems with excessively high relationships (Pallant, 2010; Rubin, 2012). In addition, the independence of these variables was tested with the KMO (Kaiser-Meyer-Olkin) value and the Bartlett's test of sphericity value to examine the appropriateness of the variable groups. It was found that the KMO value obtained was 0.92, which is greater than 0.8 and is very suitable for factor analysis. The Bartlett's test of sphericity value is statistically significant (Bartlett's Test = 589.70, df = 153, Sig = .000). Therefore, these variables do not have problems with multicollinearity, so they are suitable for analyzing the measurement model and the developed research model (Hair et al., 2010), as shown in Table 3 as follows:

Table 3 : Correlation coefficient of observed variables

	ITI	DPC	TI	SCC	AI	TD	ATC	EP	RS	GPS	AII	ER	IC	RGGE	Ref	WRR	CS	TRO
X	4.48	4.32	4.71	3.93	4.12	3.99	4.71	4.62	4.41	4.04	4.43	4.00	4.09	4.08	3.84	4.39	4.02	3.81
SD	0.52	0.51	0.57	0.63	0.84	0.54	0.48	0.52	0.52	0.71	0.64	0.68	0.49	0.72	0.57	0.73	0.52	0.69
ITI	1	0.12	0.26	0.17	0.15	0.35	0.24	0.15	0.18	0.25	0.27	0.23	0.19	0.12	0.30	0.23	0.23	0.17
DPC		1	0.12	0.18	0.38	0.26	0.25	0.07	0.40	0.15	0.23	0.20	0.16	0.10	0.12	0.32	0.25	0.21
TI			1	0.29	0.20	0.19	0.14	0.17	0.14	0.11	0.08	0.18	0.26	0.20	0.05	0.03	0.12	0.42
SCC				1	0.15	0.15	0.21	0.15	0.11	0.28	0.20	0.21	0.27	0.23	0.21	0.03	0.18	0.25
AI					1	0.118	0.24	0.21	0.77	0.24	0.61	0.13	0.23	0.56	0.69	0.70	0.39	0.60
TD						1	0.16	0.14	0.23	0.17	0.28	0.13	0.12	0.10	0.26	0.22	0.19	0.23
ATC							1	0.86	0.47	0.28	0.20	0.46	0.24	0.10	0.28	0.17	0.02	0.17
EP								1	0.5	0.31	0.18	0.29	0.19	0.17	0.15	0.20	0.21	0.27
RS									1	0.27	0.59	0.31	0.26	0.55	0.28	0.67	0.48	0.43
GPS										1	0.17	0.19	0.27	0.12	0.17	0.28	0.22	0.24
AII											1	0.17	0.24	0.43	0.42	0.34	0.30	0.57
ER												1	0.12	0.15	0.21	0.38	0.28	0.13

	ITI	DPC	TI	SCC	AI	TD	ATC	EP	RS	GPS	AII	ER	IC	RGGE	Ref	WRR	CS	TRO
IC													1	0.11	0.19	0.20	0.14	0.23
RGGE														1	0.23	0.41	0.54	0.37
Ref															1	0.35	0.30	0.62
WRR																1	0.27	0.11
CS																	1	0.28
TRO																		1

**p-value < 0.01

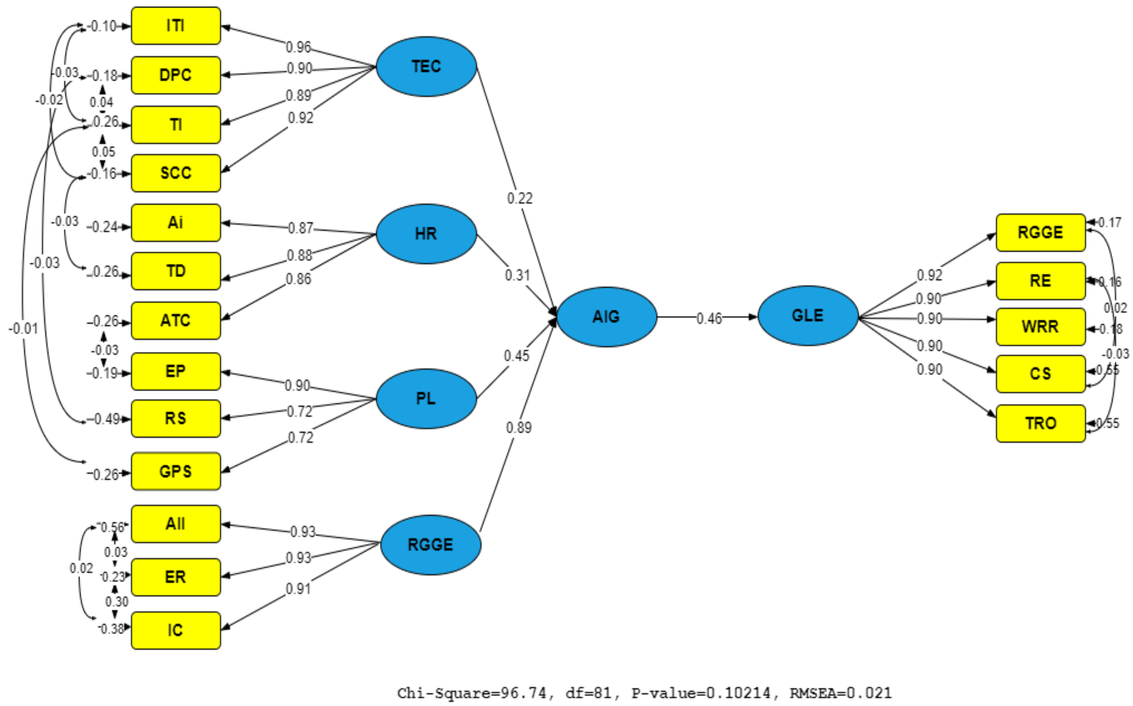
Model analysis results The results of the examination found that the chi-square value = 589.70 was statistically significant at the 0.10 level (p-value = 0.10). The relative fit index (CFI) was 1.00, the general fit index (GFI) was 0.96, and the AGFI was 0.94. All indices passed the criteria, indicating that the model was consistent with the empirical data (Hair et al., 2010), as shown in Table 4 as follows:

Table 4 : Results of the consistency test of the empirical model with the theoretical model (prototype model)

Statistics used for verification	Calculated values	Interpretation
Chi-square	96.74	Passed the criteria
Chi-square/df	1.20	Passed the criteria
df	81	Passed the criteria
p-value	0.10	Passed the criteria
CFI	1.00	Passed the criteria
GFI	0.96	Passed the criteria
AGFI	0.94	Passed the criteria
RMSEA	0.02	Passed the criteria

The analysis results found that all index values passed the criteria, indicating that they were consistent and consistent with empirical data, as shown in Figure 2.

Figure 2 Results of the causal relationship analysis of causal factors affecting the role of artificial intelligence (AI) in increasing the efficiency of green logistics.



The analysis results found that the variables that are components of the causal variables and the results of the causal factors affecting the role of artificial intelligence (AI) in increasing the efficiency of green logistics have direct influence values, indirect influence values, and total influence values, divided by the research hypothesis, as shown in Table 5.

Table 5 : Direct influence (DE), indirect influence (IE), and total influence (TE)

Causal variable	Outcome variable		
	Green Logistics Efficiency (GLE)		
	DE	IE	TE
Technology (TEC)	0.35**	0.15**	0.50**
Human resources (HR)	0.25**	0.10**	0.35**
Policy and law (PL)	0.30**	0.20**	0.50**
Economy (EC)	0.20**	0.10**	0.30**

**p<0.01, *p<0.05

From Figure 2 and Table 5, the analysis results show that:

(1) Technology (TEC) has a positive effect on the role of AI in enhancing green logistics efficiency (GLE), with an influence value of 0.35, an indirect influence value of 0.15, and a total influence value of 0.50, which are statistically significant at the 0.01 level. Therefore, research hypothesis 1 is accepted.

(2) Human resources (HR) has a positive effect on the application of AI in green logistics (GLE), with an influence value of 0.25, an indirect influence value of 0.10, and a total influence value of 0.35, which are statistically significant at the 0.01 level. Therefore, research hypothesis 2 is accepted.

(3) Policy and law (PL) have an effect on the application of AI in sustainable logistics (GLE), with an influence value of 0.30, an indirect influence value of 0.20, and a total influence value of 0.50, which are statistically significant at the 0.01 level. Therefore, research hypothesis 3 is accepted.

(4) Economy (EC) has an effect on the ability to apply AI to enhance environmental logistics efficiency. (GLE) with an influence value of 0.20, an indirect influence value of 0.10, and a total influence value of 0.30, which were statistically significant at the 0.01 level. Therefore, research hypothesis 4 was accepted.

4. Conclusion and discussion

1. Technological factors have a positive effect on the role of AI in enhancing the efficiency of green logistics, with a statistical significance level of 0.01. Therefore, Hypothesis 1 is accepted. Technology is an important foundation to support the development of AI for green logistics systems. The use of modern technologies such as big data analytics and cloud technology allows logistics systems to predict demand in advance, optimize transportation routes, and effectively reduce energy consumption (Wang et al., 2020). For example, an AI-based intelligent transportation routing system can reduce transportation distances and greenhouse gas emissions (Bai & Sarkis, 2021).

2. Human resource factors have a positive effect on the application of AI in green logistics, with a statistical significance level of 0.01. Therefore, Hypothesis 2 is accepted. Human resources are an important part of driving the application of AI in organizations. The ability to develop and use AI systems depends on the skills and expertise of the relevant personnel. Training employees to use automation and data management effectively is essential (Singh & Sahu, 2022). Organizations that prioritize human resource development will be able to fully utilize AI and gain a competitive advantage (McKinsey & Company, 2021).

3. Policy and legal factors have a statistically significant effect on the adoption of AI in sustainable logistics at a level of 0.01, thus accepting hypothesis 3. Policy and law formulation that supports sustainable AI use plays an important role in driving changes in the logistics sector. Laws related to personal data protection and cybersecurity help build confidence in the use of AI technologies (Russell & Norvig, 2021). In addition, government support through tax incentives and research funding can reduce barriers to adapting to an environmentally friendly logistics system (UN, 2022).

4. Economic factors have a statistically significant effect on the ability to apply AI to improve environmental logistics efficiency at a level of 0.01, thus accepting hypothesis 4. The ability to invest in AI technology depends on the economic strength of the organization. The cost of developing and maintaining intelligent systems can be a significant obstacle for small companies. However, reducing long-term operating costs with AI is a significant advantage. (International Transport Forum, 2022) Organizations that are able to allocate economic resources effectively will be able to sustainably increase their competitiveness (McKinsey & Company, 2021).

This research has generated new knowledge that is beneficial to the development and application of AI in green logistics systems in several dimensions, as follows:

1. Integration of intelligent technology with logistics systems: The research results show that the use of AI in green logistics can significantly reduce environmental impacts through efficient transportation routing and intelligent warehouse management (Wang et al., 2020).

2. Developing human skills to support the use of AI: Training and developing human skills play an important role in promoting the most effective use of AI. Organizations that invest in developing human resources can reduce the complexity of adapting to automation (Singh & Sahu, 2022).

3. The role of policies and laws in creating an environment conducive to the use of AI: Research indicates that government support and clear legal frameworks, such as data protection laws and cybersecurity, can increase the confidence of organizations and stakeholders (Russell & Norvig, 2021).

4. Economic impact and investment: Investing in AI technology is considered a long-term competitive advantage. This research found that reducing costs through the use of AI can help organizations compete sustainably, even in volatile economic conditions (McKinsey & Company, 2021).

Recommendations for future research

To expand the research scope and further enhance knowledge on the application of AI in environmental logistics systems, the researchers recommend the following:

1. In-depth study of forecasting capabilities: Further research should be conducted on AI algorithms that can accurately predict product demand and plan logistics management in advance.

2. Sustainability assessment in various dimensions: The impact of AI on sustainability in economic, social, and environmental dimensions should be studied, along with the development of appropriate assessment tools.

3. Comparative research at the international level: International studies should be conducted to compare the use of AI in logistics systems in different countries to identify best practices.

4. Development of new business models: Research should be conducted on business models that are consistent with the use of AI technology to increase competitiveness in the logistics industry.

5. Development of risk management tools: Research should focus on the development of risk management tools in logistics that use AI to predict and reduce the impact of unexpected events.

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