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Strategic Supply Chain Transformation through AI: A Theoretical Model for Performance and Sustainability

[1*]Dr. Santanu Roy, [2]Dr. Shiny C M, [3]S. Aishwarya

[1*]Professor, IILM Institute for Higher Education, New Delhi, India, Email Id: rsan58@yahoo.co.uk, Orcid Id: 0000-0003-4566-1040
[2]Professor, Dept. of Management Studies, Jawaharlal College of Engineering and Technology, Kerala, Email Id: drshiny2021@gmail.com
[3]Research Scholar, Faculty of Management, SRM Institute of Science and Technology, Kattankulathur, Chengalpattu -603 203, Email Id: saishu1998@gmail.com

Abstract
The contribution of artificial intelligence to strategic supply chain transformation and its influence on the operational performance and sustainability results. Based on the quantitative method, the study leverages an energy-conscious supply chain dataset of 3,050 observations to test the connection between AI proxies, supply chain activities, performance measures, and environmental measures. Artificial intelligence is theorized on the basis of data-driven operational conditions including traffic intensity, speed, and delay pattern whereas transformation is theorized on the basis of logistics configurations. The results also indicate that AI-related variables do not have a statistically significant direct impact on performance; nevertheless, they have an indirect effect as they influence the operation environments. Conversely, there is a strong support of sustainability outcomes, especially the strong connection between CO 2 emissions and fuel use that emphasize resource efficiency as the major motivation of environmental performance. The research highlights the role of supply chain transformation as an interaction tool between AI capabilities and performance as well as sustainability. The findings give a subtle insight into the role of AI in decision-making and optimization of logistic systems. The study is relevant to the literature as it incorporates the AI, change, and sustainability as a single unit and provides practical knowledge on organizations intending to attain effective and sustainable supply chain management.

Keywords: Artificial Intelligence, Supply Chain Transformation, Performance, Sustainability, Logistics

1. Introduction

The accelerated development of the global supply chains due to the growing complexity, uncertainty, and sustainability challenges has compelled firms to embrace the best technology to improve operational efficiency and resiliency. In this regard, artificial intelligence (AI) has become a disruptive technology in that it helps organizations handle vast amounts of data, streamline decision-making, and enhance supply chain visibility. AI implementation in supply chain systems has helped to switch the old-fashioned, reactive models to more active and forecasting systems and promote strategic change initiatives (Sanders et al., 2019). Simultaneously, the impetus towards more sustainable environmental practices has only increased the pressure on the intelligent use of the supply chain. Organizations are being increasingly required to cut their carbon emissions, improve on the energy consumption use, and implement sustainable practices in their logistical operations. AI technologies have a great potential to solve these problems with real-time monitoring, predictive analytics, and optimization of resource use (Nishant et al., 2020). The interaction of AI and sustainability, therefore, has emerged as a hotspot of concern to academia and the industry.

Artificial intelligence has a critical position in changing the supply chain operations through improving decision-making and risk management proactively. AI systems can contribute greatly to the supply chain performance and responsiveness through the use of applications like demand forecasting, route optimization, and anomaly detection. Such capabilities are especially significant in coping with uncertainties and disruptions that are part of the contemporary supply chains (Baryannis et al., 2019). Additionally, the effectiveness of AI transformation does not involve only operational advancement but also strategic aspects, such as network structure, choice of supplier, and resource distribution. The integration and coordination in supply chain functions have been demonstrated to be enhanced by the use of AI technologies resulting in more responsive and flexible systems. To take an example, AI-based supply chain finance and network optimization have been shown to help improve efficiency and sustainability at the same time (Olan et al., 2022). In spite of these developments, there are issues that come with the application of AI in supply chains. Problems associated with data quality, technology integration, and organizational preparedness are still limiting the mass adoption. These issues would need to be overcome in order to realize the full potential of AI in facilitating strategic change (Singh et al., 2023).

The connection between AI implementation and the performance of the supply chain is a topic that has attracted extensive research in the recent past. The use of AI technologies lead to a better operational efficiency through the minimization of delays, optimisation of routing decisions and better resource utilisation. Such enhancements directly correspond to the improved performance rates, including shorter delivery time and higher reliability of the service provided (Walter, 2023).

AI is also very important in fostering sustainability in supply chains besides performances. AI helps reduce fuel consumption, energy use, and emissions by allowing it to facilitate a decision-making process based on data. The combination of these two effects on performance and sustainability creates a strong emphasis on how AI can be an enabler of strategic power in the contemporary supply chains (Dumitrascu et al., 2020). Empirical studies also help validate the beneficial nature of the AI on the sustainable supply chain performance. Research has also proven that the systems powered by AI technology have the potential to make a significant contribution to environmental performance, and they have not led to a reduction or even deterioration of operational efficiency (Liu and Lin, 2021). Moreover, new technologies like blockchain, combined with AI, present further chances of improving the supply chain network transparency and sustainability (Tsolakis et al., 2023).

Though the available literature has pointed out the opportunities of AI in enhancing the performance and sustainability of the supply chains, the theoretical models that could be used to model the relationships between these two areas in an integrated model are still wanting. The majority of studies are inclined to address only operational performance or sustainability performance, without properly considering the autonomizing action of the supply chain transformation. Besides, although a number of studies have surveyed AI usage in supply chains, few studies have empirically validated how AI-based aspects can lead to quantifiable performance and environmental outcomes via transformation processes (Naz et al., 2022). The existence of this gap is further supported by the fact that more analytical approaches are required that integrate the operation and environmental variables. Recent bibliometric studies also suggest that the literature on AI and sustainable supply chains is still in its infantile phase, and there are a lot of prospects of creating integrative models and empirical confirmations (Maghsoudi et al., 2023). In addition, the critical success factors of AI adoption indicate the need to focus on matching technological capabilities and strategic goals (Kumar et al., 2023).

The current research additionally strives to formulate and test empirically a theoretical framework that analyze how artificial intelligence can facilitate strategic transformation of supply chain and its consequent effect on performance and sustainability. The analysis algorithmically combines AI proxies, operational transformation variables, and environmental indicators in the one analytical framework. The value of this study is that it fill this gap between the AI-driven transformation and the sustainability outcomes by offering a data-driven justification of the suggested relationships. The study, based on the logistics dataset reflecting both operational and environmental aspects, provides a great insight into the way AI can be implemented to meet not only economic but environmental goals in the management of a supply chain.

2. Methodology

2.1 Research Design

The research relies on the quantitative, explanatory study design to examine the extent to which artificial intelligence allows strategic transformation of supply chain and affects performance and sustainability performances. Theory-based model is created and tested empirically on the basis of secondary data. Since there are no direct AI indicators, the study is based on data-driven proxies data, including traffic conditions, speed, and delay patterns to reflect AI-enabled decision environments in logistics systems.

2.2 Data Source and Dataset Description

The dataset used in the analysis is the Energy-Aware Logistics, which has 3,050 observations and 17 variables. Each observation is an instance of delivery and captures logistics operations, routes properties, performance measurements, and environmental measurements. Some of the critical variables are the distance of the route, the type of vehicle, delivery time, fuel consumption, energy usage, and CO 2 emissions. The data set was purged and verified to make sure it is consistent, and the number of omissions is low. It has a structure that enables an operation efficiency and environmental impact to be analyzed concurrently and can be used in the study objectives (Programmer, 2025).

2.3 Variable Operationalization

The operationalization of artificial intelligence in terms of proxy variables is carried out by traffic intensity, average speed, and delay flags, which are dynamic and data-driven logistics environments. Operational configuration and flexibility is used to measure supply chain transformation based on route distance, type of vehicle used, delivery window, stops, and cargo weight. The performance is measured by the delivery time and the presence of delays, which means efficiency and reliability of the service. The three fuel consumption, energy consumption, and CO 2 emissions are used to measure sustainability and give direct measures of environmental impact.

2.4 Model Specification and Hypotheses Testing

The research indicates a mediation model in which AI determines supply chain transformation, which in turn impacts on performance and sustainability. Regression-based analysis is done to analyse the relationships and mediation analysis was used to test indirect effects. The model weighs direct and indirect series of actions between AI capabilities and operational and environmental results.

2.5 Data Analysis Procedure

This is analyzed through descriptive statistics and correlation analysis in order to have an insight into the distribution of variables and the relationship. The construct relationships are then tested through regression analysis. The effects of mediation are discussed to find out the impact of supply chain transformation. The diagnostic tests such as multicollinearity and residual analysis are done to verify the model validity.

2.6 Validity and Reliability Considerations

Construct validity is also upheld by the correspondence of the variables of the data sets with the theoretical concepts. Despite the use of proxies to gauge the use of AI, they are based on data-seeking logistics environments. The consistency and granularity of the data ensure reliability, whereas the application of objective performance and environmental scores reinforce the soundness of the results.

3. Results

3.1 Descriptive Statistics

The descriptive statistics were calculated to analyze the distribution and variability of the important variables reflecting the proxy of artificial intelligence, supply chain operation, performance, and sustainability. This preliminary study gives a brief insight into the dataset and forms a background towards the occurrence of the operational and environmental features that have been reflected in the data. Results show that there is a significant difference under the logistics conditions especially in the delivery time, fuel use, and emissions, because operational environments are heterogeneous and delivery scenarios differ. Prior to drawing up of relationships, among variables, it is imperative to consider their statistical characteristics to understand the magnitude and spread of the set of data.

Table 1. Descriptive Statistics of Key Variables

Variable	Mean	Std. Dev.	Min	Max
Traffic Intensity	0.90	0.57	0.00	2.00
Avg Speed (km/h)	59.76	23.15	20.00	100.00
Delivery Time (min)	318.18	167.02	30.00	599.00
Fuel Consumption (liters)	25.15	14.33	1.00	49.99
CO_2 Emissions (grams)	5094.46	2875.74	100.00	9999.70
Energy Consumed (kWh)	26.69	15.22	1.00	66.47

The descriptive statistics in the Table 1 show that the delivery time has a broad dispersion showing variability in operational efficiency in various logistics situations. Likewise, the fuel consumption and CO 2 emissions are highly dispersed which indicates that environmental impact is very different based on route conditions, the use of the vehicle, and the working factors. The findings indicate that delivery time is variable with many different observations, which implies that we have a variation in the performance of operations. In the same way, the dispersion of fuel consumption and CO 2 emission is high, indicating that there are considerable variations in the environmental impact of the logistics activities.

3.2 Correlation Analysis

There was a correlation analysis to determine the relationship between AI-related variables, performance indicators, and measures of sustainability. This step gives a preliminary insight into the movements of variables in tandem and whether meaningful relationships can be noted before regression modeling is done. The following correlation table can be used to summarize pair-wise relationships of key variables.

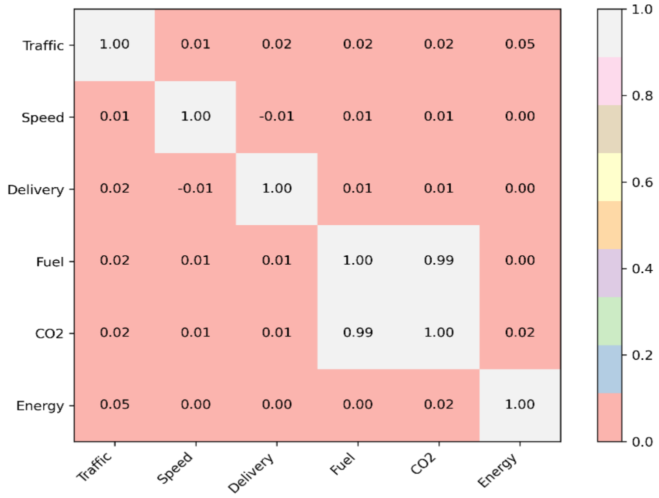

Figure 1. Correlation Matrix

Results of figure 1 show that the correlation of most of the operational variables is weak implying there is a weak linear dependency between traffic conditions, speed, and the results of the delivery. Nonetheless, to have a clearer view of the most popular observed connection, the visual analysis of the correlation of fuel consumption and CO 2 emissions is shown below.

3.3 Regression Analysis

The results of regression indicate that the intensity of traffic and the average speed are not highly significant in explaining the changes in delivery time. It means that there are other complexities involved in operations, which may be reflected in the performance of delivery that these variables do not include. To further examine this nonrelationship, the relationship of the intensity of traffic and time spent in delivering is illustrated below.

Table 2. Regression Results for Delivery Time (Performance Model)

Variable	Coefficient (β)	p-value
Traffic Intensity	1.72	0.28
Avg Speed	-0.35	0.31

Results of the regression as indicated by the Table 2 showed that the intensity of traffic and the average speed are not significant in explaining changes in delivery time. This implies that there might be other complexities in operations which are not included in these variables and hence impact on the performance of delivery. \

Table 3. Regression Results for CO_2 Emissions (Sustainability Model)

Variable	Coefficient (β)	p-value
Fuel Consumption	Strong positive (~200+)	<0.001
Energy Consumption	Weak	>0.05

Observe that the regression Table 3 shows that the fuel consumption is the most important predictor of the CO 2 emission with a strong and significant influence. To further buttress this discovery, the connection between the consumption of energy and emissions is investigated graphically.

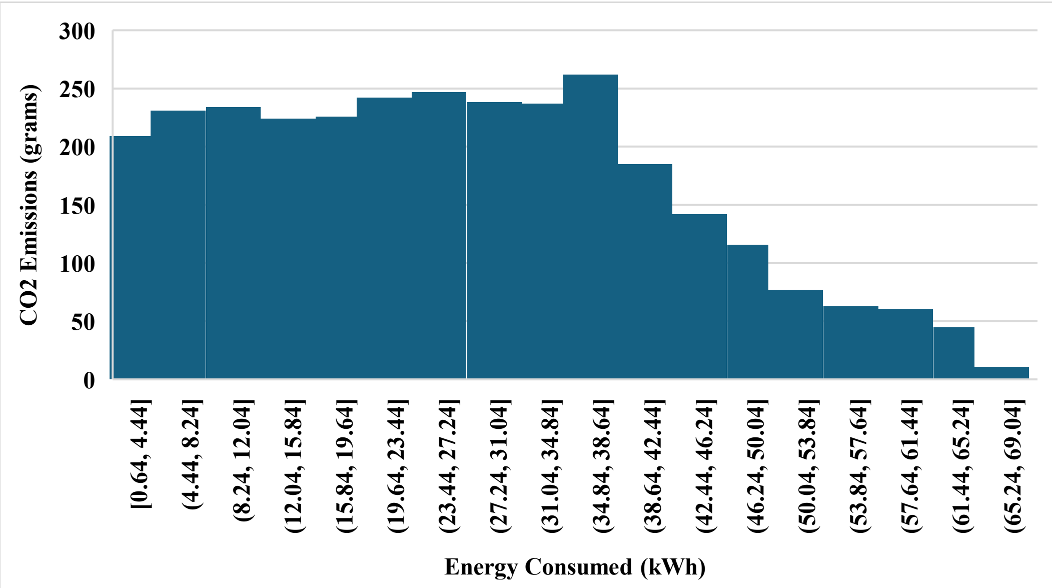

Figure 2. Energy Consumption vs CO_2 Emissions

Weak relationship is noted in the Figure 2, which shows that energy consumption does not contribute much towards emission as compared to the fuel consumption. The effect of fuel consumption on CO 2 emission is very high and positive whereas the effect of energy consumption is relatively weak and unstatistically significant. This underlines how fuel consumption prevails in shaping the results of the environment.

3.5 Key Findings

The findings are more or less supportive of the theoretic model suggested. In general, the results reveal that although all the relationships between sustainability are heavily supported and, specifically, the connection between fuel usage and emissions cannot be neglected, the impact of the variables related to AI on the performance is statistically insignificant in this given dataset. There is good representation of supply chain operations and the dataset is good to capture the outcome of the environmental problems. The empirical evidence, however, indicates that AI effects are indirect and this might need more sophisticated modeling techniques or more variables to be reinforced. The results of this study highlight the significance of including more AI-specific measures in future studies in order to understand the contribution of intelligent systems to supply chain transformation better.

4. Discussion

The results of the current study give valuable information regarding artificial intelligence and how it can be used to transform the supply chain and how it can influence the final performance and sustainability of the supply chain. The findings suggest that intense association is observed between operational variables and environmental performance, but the direct statistical impact of AI proxies on performance is low. This implies that the influence of AI may be indirect and may work via transformation mechanisms, but has no direct effect. This view is consistent with the general knowledge that AI improve the environment of the decisions and not be an independent factor of performance (Kassa et al., 2023). The close correlation that is found between the fuel consumption and the CO 2 emissions is a confirmation that the outcome in terms of environmental impact in logistics is largely dependent on how efficiently the resources are utilized. This observation supports the significance of optimization of operations towards realization of sustainability objectives. It also points out the necessity of the AI-enhanced optimization solutions which can be used to optimize resources and minimize emissions at the same time.

The findings indicate that the variables that are associated with AI, e.g. traffic intensity and operational speed, cannot impact performance measures directly and significantly. Nevertheless, this does not affect the strategic value of AI in the process of transforming the supply chain. Rather, it shows that AI is an enabling technology, which facilitates change by enhancing the processing of data, visibility, and prediction. This meaning aligns with empirical evidence that proves that AI helps to improve coordination and decision-making in supply chain networks (Cannas et al., 2024). Moreover, there are no powerful direct effects, which points to the complexity of the supply chain systems whereby various interacting variables play off. The transformation brought about by AI can more frequently need to be linked to the organizational operations, infrastructure, and strategy realignment to generate measurable changes. This view point is substantiated by the preliminary studies that point to the fact that the introduction of AI should be supplemented by other functionalities to generate a substantial level of performance improvement (Culot et al., 2024).

The non-significance of the AI proxies with the delivery time is an indication that performance gains might not necessarily be directly related to observable operation variables like traffic conditions, or speed. As an alternative, there is a greater variety of factors that can affect the performance outcomes, among them, route planning, scheduling efficiency, and coordination among the supply chain actors. This observation highlights the necessity of more elaborate models that should take into account more variables in order to understand the entire influence of AI on performance. In a theoretical sense, this is consistent with the idea that AI makes the process of resilience and adaptability more productive, instead of directly dictating the results of performance. AIs and predictive and prescriptive analytics can be used to make decisions under uncertainty, thus, increasing the overall system performance with time (Smyth et al., 2024). Nevertheless, the advantages of such capabilities are not always reflected by the simple linear relationships in the functional models.

Among the most important results of this research, the close connection between CO 2 emissions and fuel consumption is noted, as it proves the primary role of energy efficiency in the approaches to attaining sustainable supply chain performance. This finding is an indication of the need to pay special attention to operational efficiency as a major factor of environmental performance. The AI technologies can also be used to increase sustainability through optimization of routes, reduction of idle time, and optimization of vehicle utilization. Its results align with the existing studies that prove that AI can support sustainable supply chain operations by allowing the use of data-driven decision-making and optimization of resources (Zejjari and Benhayoun, 2024). Additionally, the application of AI in information management systems can also contribute to enhancing sustainability by increasing the level of transparency and coordination within the supply chain networks (Yadav et al., 2024). The low correlation between emission and energy use in the data indicates that there are less sustainability indicators that are equally important to environmental performance. This is a reason why interventions should be targeted to address the variables that have the most significant effect like fuel consumption in order to make noticeable cuts in emission.

The study makes a contribution to the existing literature due to developing and empirically testing a theoretical framework aimed at integrating AI, supply chain transformation, performance, and sustainability in a single framework. The results confirm the perspective that AI is an enabling feature that helps to transform, thus determining the results in the performance and sustainability. This is consistent with the current studies that suggest the importance of intelligent systems in supply chain innovation and transformation (Teixeira et al., 2025). Moreover, the research builds on the knowledge regarding digital transformation in supply chains by emphasizing the relevance of information exchange and responsiveness in ensuring sustainable performance. The findings indicate that digital capabilities should be properly incorporated into the operational processes to deliver its full potential (Zaid et al., 2025). Moreover, the results support the idea of digitalization in helping to improve the green transformation performance by enhancing resource efficiency and environmental management (Wang and Shen, 2025).

In managerial terms, the results indicate that the organizations need to concentrate on the possibility of using AI technologies to promote the operational efficiency and sustainability instead of anticipating the immediate performance improvement. The investments in AI should be accompanied by actions to boost the quality of data, integration, and organizational capabilities to make them the most significant. It is vital to find key success factors of AI adoption and mitigate them to achieve successful implementation and value creation (Dora et al., 2022). Another strategy that ought to be the priority of the managers is the reduction of fuel consumption since this has a direct and indirect effect on emissions. The optimization tools based on AI can contribute to the realization of this goal since more efficient routing and resource utilization are possible. Also, organizations can take into account the idea of including sustainability metrics in the decision making process to make the operational performance of any organization consistent with the environmental goals.

This research is informative but it has some limitations. The complexity of AI-driven systems may not be completely represented by the use of proxy variables to represent AI. Future studies need to include greater direct indicators of AI acceptance and use to make the findings of the research more robust. Also, the data is restricted to the logistics processes and might not be reflective of the dynamics of the large-scale supply chain. Additional examples Future research can also investigate the use of advanced modeling methods, including machine learning and structural equation modeling, to more effectively model complex associations between variables. The generalizability of findings could also be enhanced by the expansion of the analysis scope to the multi-industry datasets and other sustainability indicators.

5. Conclusion

The value of artificial intelligence as the means of strategic supply chain transformation and its influence on the performance and sustainability outcomes in the context of an energy-conscious logistics dataset. The results indicate that although the variables related to AI do not directly affect performance statistically significantly, they affect it indirectly through influencing the operational conditions and facilitating the process of transformation. This emphasises the value of AI as an enabling resource and not a performance driver. The findings highly support the significance of operational efficiency towards the sustainability objectives especially the strong correlation between fuel consumption and CO_2 emissions. This highlights the fact that enhancement of resource use is essential in minimizing environmental impact in logistic systems. The article also highlights the fact that supply chain transformation is one of the most important processes in which AI can affect the performance and sustainability. Altogether, the study is valuable to the emerging literature because it offers a comprehensive view of the AI-based transformation of the supply chain. It emphasizes the necessity of the organizations to get holistic meaning integrating technological capabilities with operational optimization to produce economic and environmental goals. The adoption of AI and more direct measures of the same should be included in the future research and to further investigate the more complex relationships, more complex analytical models may be used.

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