# Adoption of Industry 4.0 Technologies in E-Retailer Supply Operations and its Implications for Customer satisfaction and Sustainability

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**Abstract**
The rapid expansion of e-commerce across Asian markets has intensified operational and environmental pressures on e-retail SMEs, particularly within last-mile logistics. This study examines how Industry 4.0 (Quality 4.0) technologies influence operational efficiency and sustainability performance in supply chain management. Positioned within the broader discourse on digital innovation and sustainable enterprise development, the study conceptualizes technology adoption as a strategic capability that enables SMEs to enhance competitiveness while advancing environmentally responsible practices. A quantitative research design was employed using survey data collected from 60 professionals engaged in e-retail supply chain operations. Reliability analysis, exploratory factor analysis, and multiple regression were conducted to evaluate the relationships between digital transformation practices and performance outcomes. Four key dimensions of Industry 4.0 adoption were identified: delivery and demand planning improvements, last-mile delivery enhancements, tracking and monitoring systems, and reliability and delivery quality improvements. The findings reveal that operational efficiency is primarily driven by demand planning and digital visibility mechanisms, whereas sustainability performance is significantly influenced by last-mile delivery optimization, tracking systems, and delivery reliability. The results indicate that digital technologies support dual performance objectives, but through differentiated operational pathways. The study contributes to the understanding of how technology-enabled innovation strengthens both efficiency and sustainability in SME-led e-retail ecosystems, offering strategic implications for entrepreneurs and managers seeking to balance competitiveness with green supply chain practices.

**Keywords:** Sustainable entrepreneurship, Asian SMEs, Industry 4.0, Digital innovation, Green logistics, Supply chain sustainability

## 1. INTRODUCTION

The swift growth in e-commerce has transformed the way the world carries out retail business, bringing new opportunities to the businesses, as well as posing a great challenge. To the e-retail SMEs / entrepreneurial e-retail ventures, last mile logistics is one of the most important and dynamic aspects of the logistics process that involves the last phase in the supply chain where goods are delivered to an end destination at the doorsteps of the consumers. Increased online shopping has resulted in increased customer demands to speed, reliability, and cost-efficiency in regards to the speed of delivery. Consequently, the last mile logistics have become a center of interest among e-retail SMEs / entrepreneurial e-retail ventures who want to enhance quality of their services and remain competitive in the overcrowded market. Nevertheless, other challenges associated with this stage of the supply chain are expensive operation costs, ineffective route planning, lack of scalability, and rising need of real-time tracking and communication with the customers. Considering these issues, Quality 4.0, a multifaceted approach that incorporates innovative technologies in quality management can transform the logistics of e-retail SMEs / entrepreneurial e-retail ventures to the last mile. However, research remains limited on how Asian entrepreneurial SMEs use Industry 4.0 not only to improve operations, but to pursue sustainable entrepreneurship, inclusive growth, and long-term competitive advantage. Quality 4.0 is an expansion of the traditional approaches to quality management that is integrated with the new technologies like the Internet of Things, Big Data analytics, Artificial Intelligence, machine learning, and automation (Bousdekis et al., 2023; Idrissi et al., 2024). Through these tools, e-retail SMEs / entrepreneurial e-retail ventures are able to increase operational efficiency, improve the delivery route, and real-time decision-making processes (Bousdekis et al., 2023). Furthermore, Quality 4.0 may be used to minimize waste, enhance resource use, and eventually raise the level of customer satisfaction due to punctual and trustworthy deliveries. Although it is a crucial part of the supply chain, last mile logistics is also a particularly difficult aspect of the supply chain of e-retail SMEs / entrepreneurial e-retail ventures. There are a number of challenges that make the delivery of products to consumers complicated. High costs of last mile logistics are some of the major issues. The last mile delivery is usually a large share of overall logistics expenses. The increased cost of this last leg of the supply chain is due to factors including fuel prices, cost of labour and the need to make last minute changes to the delivery schedules (Fried & Goodchild, 2023). The costs are further increased by the complexity of small order and delivery to scattered urban and rural centres.

In Asia, rapid platform growth and SME-led e-commerce expansion have created a distinctive context where many e-retailers operate as entrepreneurial ventures. These firms face institutional constraints (infrastructure gaps, regulatory variation, logistics fragmentation) while also confronting rising sustainability pressures from consumers and policymakers (Gonzalez et al., 2023). Customers are increasingly demanding next-day or same-day delivery and placing enormous stress on e-retail SMEs / entrepreneurial e-retail ventures to streamline their work and minimize the delays impacting customer satisfaction and loyalty adversely. The inefficiency in route optimization, which is usually caused by the availability of old or inadequate technologies, may lead to a waste in time, fuel, and resources. Consumers are also demanding an end-to-end visibility of the delivery process, order placement to the ultimate delivery. Lots of e-retail SMEs / entrepreneurial e-retail ventures are yet to offer real-time tracking and communication, which causes frustration in consumers when there is no precise update on the time of delivery or its state. Processes such as inefficient use of routes, fossil fuel-based vehicles, and delivery services that are not environmentally-friendly also add to the unsustainable nature of most last mile operations (Nogueira et al., 2025). Most of these challenges could be solved with the help of the application of Quality 4.0 principles. It is possible through the implementation of data analytics and AI to enable e-retail SMEs / entrepreneurial e-retail ventures to optimize delivery routes, forecast demand better, and manage the inventory levels (Bousdekis et al., 2023; Idrissi et al., 2024). In this study, the researched problem is to investigate how Quality 4.0 concepts affect last mile logistics within the e-retail industry and how these technologies are able to solve the dynamics of high operations expenses, delays in delivering products, inefficiency, and a lack of visibility, as well as address the issue of sustainability. The research will also offer meaningful information on how e-retail SMEs / entrepreneurial e-retail ventures can utilize emerging technologies to enhance their last mile delivery processes by exploring how Quality 4.0 can help the study achieve better results in terms of supply chain management and logistics performance. Finally, the study will aim to add to the knowledge of how Quality 4.0 will design a more efficient, cost-effective, and customer-centric last mile logistics ecosystem, and both e-retail SMEs / entrepreneurial e-retail ventures and consumers will gain.

## 2. LITERATURE REVIEW

Sustainable entrepreneurship research emphasizes how SMEs create value by integrating innovation with environmental and social goals. In Asia, institutional diversity, infrastructure gaps, and fast-growing digital markets shape how entrepreneurial firms innovate and scale sustainably (Alkhodair & Alkhudhayr, 2025; Di Nardo et al., 2025).

The last mile logistics portion of the supply chain has proven a point of keen interest among the e-retailers due to its direct influence on customer satisfaction, efficiency of operations and business profitability at large (Buldeo Rai & Dablanc, 2023). This is the last phase of delivery which involves a distribution centre to the final consumer, and is usually the most expensive and the least efficient part of the total logistics process. In the case of e-retailers, managing the last mile delivery is essential, with the rising consumer demands and demands, as well as, the need to achieve flexibility, speed, and affordability in delivery services (Christopher, 2016; Beck et al., 2025). Institutional theory suggests that regulation, logistics infrastructure, and ecosystem support influence SME technology adoption. Asian e-retail ventures often face varied last-mile governance, uneven charging infrastructure for EVs, and platform dependency—factors that shape sustainability outcomes (Gonzalez et al., 2023). Cost management is one of the major issues of last mile logistics. The research indicates that last mile delivery can take a significant share of the total logistics cost, which is sometimes as high as 28% of the total supply chain costs (Bosona, 2020; Buldeo Rai et al., 2021). These expenses are motivated by a number of factors and some of them are fuel costs, cost of maintenance of delivery vehicles, labour costs of drivers and inefficiencies in the routes. Also, the nature of urban settings where high populations are concentrated, traffic congestion, narrow streets and heavy number of delivery destinations add to the cost and time of delivery (Bosona, 2020; Fried & Goodchild, 2023).

Consumers are also more demanding about the speed of delivery and the last phase of the delivery process can cause customer dissatisfaction and even business loss. In addition, late deliveries, skip deliveries, or spoilage occurring during the last mile operations is more prevalent in the last mile, which has a powerful impact on the customer experience. Consumers demand more transparency, live tracking, and precise delivery windows, yet several e-retailers are yet to handle these qualities regularly (Salam et al., 2024; Beck et al., 2025). The next important problem of the last mile logistics is the optimization of the route. Standard route planning processes usually cannot make use of dynamic and real-time information, such as traffic congestion, weather incidents, and last minute orders. The absence of the updated information makes the logistics providers unable to adapt delivery schedules or reroute drivers, which results in inefficient operations, increased fuel usage, and more delivery errors (Tran & Gavade, 2025). Manual route planning becomes weak and archaic in cases of large number of variables to be employed like road closures, customer demands on special deliveries and customer preferences (Jawali, 2024). With the ever-increasing e-commerce, there is a rising concern as to the sustainability of the logistics operations (Buldeo Rai et al., 2021). Customers are also insisting on environmentally friendly delivery services including the use of electric cars, bicycles and drone-delivery in the major cities. Nevertheless, these solutions are promising, but they have a number of challenges (Tran & Gavade, 2025). An example is that EVs do not have as much range, have to be recharged, and may be more expensive to buy, which makes them unsuitable to all kinds of deliveries. On the same note, bike couriers and drone deliveries are limited in their speed, weather conditions, and legal factors (Marchet et al., 2014). Nevertheless, the future of sustainable logistics is an essential aspect. E-retailers are targeting to minimize their carbon footprints, yet to make a significant advancement of green logistics, technological innovation is not the sole approach but consumer behaviour and operation changes are also necessary (Buldeo Rai et al., 2021).

Green packaging, maximized vehicle loads, among others, have been adopted as major solutions in minimizing wastes and inefficiencies. Although the first move towards more environmentally friendly logistics may be expensive, the long-term outcome is anticipated to be positive, such as compliance with the policy, consumer retention, and costs reduction of operations (Dube et al., 2011; Di Nardo et al., 2025). Quality 4.0 is the notion that will combine the most recent digital technologies like Artificial Intelligence, Big Data, Internet of Things, and machine learning with the conventional quality management approaches (Qureshi et al., 2024; Alkhodair & Alkhudhayr, 2025). This can change how business organizations operate with regards to logistics and supply chain management, particularly within the last mile delivery scenario (Di Nardo et al., 2025). Routes optimization is one of the most promising ways of AI use in the last mile logistics. Using the data of the past, AI can even anticipate traffic jams or delays, allowing business to be proactive in changing the schedule and preventing expensive inconveniences (Boute & Udenio, 2021; Qureshi et al., 2024). Also, machine learning algorithms are able to evolve over time and enhance their decision-making process as an increasing amount of data is received, which means that the system will be smarter and more efficient with every iteration. For entrepreneurial SMEs, these technologies function as strategic capabilities enabling sustainable competitive advantage rather than only operational tools (Alkhodair & Alkhudhayr, 2025).

The AI is also being utilised to enhance the precision of the forecasting of the demand, which is also a significant factor in the optimisation of the inventory management (Qureshi et al., 2024). Based on the trends of customer buying behaviour, AI systems will be able to anticipate periods of demand, including the seasonal sales or promotions (Badrinarayanan, 2024). This assists the e-retailers to plan inventory more appropriately, to optimize delivery capacity and prevents overstocking or understocking that subsequently decreases last mile inefficiencies and increases expedited delivery. The IoT technologies help in monitoring and tracking deliveries and assets in supply chain in real time (Idrissi et al., 2024). Logistics providers can monitor the location, temperature, and state of the goods during transit by installing sensors on delivery vehicles and products. Also, Big Data may be used in determining bottlenecks in the logistics network where companies may optimize their delivery workflow to save fuel, avoid delays during deliveries, and save time. Using such insights, e-retailers will be able to enhance cost-effectiveness and increase quality of services (Wang et al., 2016; Qureshi et al., 2024).

The primary objective of this study is to examine how Industry 4.0 (Quality 4.0) technologies influence supply chain performance in e-retail SMEs, particularly within the context of last-mile logistics operations. Specifically, the study seeks to identify the key dimensions of Industry 4.0 adoption in e-retail supply chain processes through exploratory factor analysis and to evaluate how these technological capability dimensions affect operational efficiency and sustainability performance in supply chain management. By addressing these objectives, the study aims to provide empirical evidence on how digital transformation capabilities contribute to both efficiency enhancement and environmentally responsible logistics outcomes in e-retail supply chains. linking Industry 4.0 capability dimensions to supply chain performance outcomes. Accordingly, it is hypothesised that the adoption of Industry 4.0 Quality 4.0 has a positive impact on operational efficiency in e-retail supply chains (H1) and has a positive impact on sustainability performance in supply chain management (H2). Figure 1 shows the conceptual model on industry 4.0 capability dimensions and their connexion to the performance results in the supply chain.


**Figure 1. Conceptual Framework of Industry 4.0 Adoption and Supply Chain Performance**

## 3. RESEARCH METHODOLOGY

This research used quantitative research design to investigate the adoption of Industry 4.0 (Quality 4.0) and its contribution to operational efficiency and sustainability in last-mile supply chain management in the e-retail industry. Data were gathered through a structured questionnaire by professionals involved in supply chain and logistics operation in Asian e-retail SMEs, including managers, founders, and operational stakeholders, for a total of 60 professionals. Responses were measured using a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5). Industry 4.0 adoption was treated as the independent variable and encompassed practices such as AI-based demand forecasting, IoT-enabled tracking systems, automation, robotics, digital monitoring tools, and data analytics. The dependent variables were operational efficiency, reflecting improvements in coordination, cost control, and delivery performance, and sustainability in supply chain management, referring to environmentally responsible logistics practices such as emission reduction and green last-mile delivery. Reliability analysis, exploratory factor analysis with varimax rotation, and multiple regression analysis were conducted to assess the relationships between digital capability dimensions and the two performance outcomes.

### *Data Analysis and Interpretation*

The reliability test was done on all 32 variables considered in the study. The Cronbach's alpha was found to be 0.788 indicating that the variables taken for the study are reliable. The reliability analysis results are presented in Table 1.

**Table 1. Reliability Statistics for the Measurement Scale**

| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items | N of Items |
|---|---|---|
| .788 | .792 | 32 |

The exploratory factor analysis is done to find the "major technological capability dimensions perceived by logistics professionals. Orthogonal rotation with varimax is applied in the test. The latent root criterion is used for the extraction of factors. The table 2 shows the KMO Bartlett's test. The Kaiser Meyer Olkin measure of sampling adequacy is above 0.772 indicating that a factor analysis can be done with this data.

**Table 2. KMO and Bartlett's Test of Sampling Adequacy**

| **Kaiser-Meyer-Olkin Measure of Sampling Adequacy** | | **.772** |
|---|---|---|
| Bartlett's Test of Sphericity | Approx. Chi-Square | 2344.512 |
| | df | 642 |
| | Sig. | .000 |

The factor analysis is done to extract factors and Varimax rotation with Kaiser Normalization to simplify and enhance the interpretability of the factor structure. This combination is commonly used in factor analysis when the goal is to identify and understand the underlying factors influencing the observed variables. As shown in Table 3, four components emerged after varimax rotation, representing distinct dimensions of Industry 4.0 adoption.

**Table 3. Rotated Component Matrix for Industry 4.0 Adoption Dimensions**

**Components**

| | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| 1 AI for route optimisation improves delivery efficiency | .679 | | | |
| 2 Machine learning predicts demand spikes effectively | .579 | | | |
| 14 IoT enhances customer communication during delivery | .535 | | | |
| 16 Big Data improves demand forecasting | .400 | | | |
| 22 Big Data reduces fuel wastage in logistics | .668 | | | |
| 28 Drones improve rural and hard-to-reach deliveries | .501 | | | |
| 5 AI minimises operational cost overruns | .601 | | | |
| 19 Analytics supports dynamic rerouting decisions | .543 | | | |
| 6 ML adapts and improves logistics over time | .592 | | | |
| 4 Predictive analytics improves customer satisfaction | | .494 | | |
| 11 IoT reduces uncertainty in delivery operations | | .419 | | |
| 18 Big Data enables better delivery scheduling | | .541 | | |
| 20 Customer insights from data improve satisfaction | | .525 | | |
| 24 Drones speed up delivery in congested areas | | .578 | | |
| 25 Robotics in warehouses improve sorting efficiency | | .567 | | |
| 21 Data-driven insights reduce last-mile delays | | .404 | | |
| 26 Automation lowers last-mile delivery cost | | .523 | | |
| 3 AI-based decision-making reduces delivery delays | | | .595 | |
| 8 IoT sensors enable real-time vehicle tracking | | | .404 | |
| 12 IoT improves coordination of drivers and dispatch | | | .602 | |
| 27 Robots minimise human errors in delivery | | | .519 | |
| 15 IoT ensures visibility across the logistics network | | | .576 | |
| 13 IoT alerts help prevent vehicle breakdown delays | | | .573 | |

| | | | | |
|---|---|---|---|---|
| 10 IoT provides accurate delivery status to customers | | | .564 | |
| 7 AI systems enhance overall delivery reliability | | | | .473 |
| 23 Autonomous vehicles reduce labour dependency | | | | .429 |
| 17 Data analytics identifies delivery inefficiencies | | | | .621 |
| 9 Smart sensors monitor parcel conditions during transit | | | | .503 |
| 30 Robotics improve speed and reliability of delivery | | | | .514 |
| 29 Automation ensures accuracy in parcel handling | | | | .545 |

The cumulative percentage of variance that the factors would explain would be the cumulative sum of the eigenvalues, which in this case is 10.655% of the first factor. This is the percentage of total variation of the observed variables which is attributed to the extracted factors. The eigenvalue of the first factor is significantly higher than the other factors. Factors that have an eigenvalue that is bigger than one is normally significant in the factor analysis. Here, it seems that the former factor is the most important and that is why there is a considerable share of a variance. The factor analysis has 4 factors that are extracted with an Eigen value greater than 1. The present solution index explains 41.572 per cent of the total variation. The initial eigenvalues and percentage of variance explained by each factor are presented in Table 4.

**Table 4: Initial Eigenvalues and Total Variance Explained**

**table 4 Initial Eigen Values**

| | **Total** | **% of Variance** | **Cumulative %** |
|---|---|---|---|
| 1 | 2.596 | 12.655 | 12.655 |
| 2 | 2.382 | 10.939 | 23.594 |
| 3 | 2.180 | 9.268 | 32.862 |
| 4 | 2.013 | 8.710 | 41.572 |

The 4 factors extracted from the factors analysis are also mentioned in the table below in detail along with the statements and the factor loading values. The four Factors are Delivery and Demand planning related improvements, Last Mile delivery related improvements, Tracking and delivery status related improvements and Reliability and delivery quality related improvements. These four dimensions represent core technological capability areas through which Industry 4.0 adoption influences operational efficiency and sustainability outcomes and environmental sustainability outcomes among Asian e-retail SMEs.

**Table 5. Summary of Factor Analysis**

| **No:** | **Factors** | **Statements** |
|---|---|---|
| Factor 1 | Delivery<br>and<br>Demand planning<br>related improvements | AI for route optimisation improves delivery efficiency<br>Machine learning predicts demand spikes effectively<br>IoT enhances customer communication<br>Big Data improves demand forecasting<br>Big Data reduces fuel wastage in logistics<br>Drones improve rural and hard-to-reach deliveries<br>AI minimises operational cost overruns<br>Analytics supports dynamic rerouting decisions<br>ML adapts and improves logistics over time |
| Factor 2 | Last<br>Mile delivery related<br>improvements | Predictive analytics improves customer satisfaction<br>IoT reduces uncertainty in delivery operations<br>Big Data enables better delivery scheduling<br>Customer insights from data improve satisfaction<br>Drones speed up delivery in congested areas<br>Robotics in warehouses improve sorting efficiency<br>Data-driven insights reduce last-mile delays<br>Automation lowers last-mile delivery cost |

| | | |
|---|---|---|
| Factor 3 | Tracking and delivery status related improvements | AI-based decision-making reduces delivery delays<br>IoT sensors enable real-time vehicle tracking<br>IoT improves coordination of drivers and dispatch<br>Robots minimise human errors in delivery<br>IoT ensures visibility across the logistics network<br>IoT alerts help prevent vehicle breakdown delays<br>IoT provides accurate delivery status to customers |
| Factor 4 | Reliability and delivery quality related improvements | AI systems enhance overall delivery reliability<br>Autonomous vehicles reduce labour dependency<br>Data analytics identifies delivery inefficiencies<br>Smart sensors monitor parcel conditions during transit<br>Robotics improve speed and reliability of delivery<br>Automation ensures accuracy in parcel handling |

Regression is carried out to study the relationship between variables and to determine how one or more independent factors influence a dependent outcome. In this study, we conducted regression analysis to find the impact of the factors from the factor analysis on the two dependent variables, which are Operational Efficiency and Sustainability in SCM. The independent variables are the four factors extracted from the factor analysis are Delivery and demand planning related improvements (V32), Last-mile delivery related improvements (V33), Tracking and delivery status related improvements (V34) and Reliability and delivery quality related improvements (V35). The two dependent variables are Operational Efficiency and Sustainability in SCM. The results of Regression Model 1, including the model summary, ANOVA, and coefficient estimates, are presented in Tables 6, 7, and 8.

**Table 6. Model Summary for Regression Analysis Predicting Operational Efficiency**

| **Regression Model 1** | | | | |
|---|---|---|---|---|
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
| 1 | .691[a] | .478 | .439 | .916 |

**Table 7. ANOVA Results for Regression Model Predicting Operational Efficiency**

| **Source** | **SS** | **df** | **MS** | **F** | **p** |
|---|---|---|---|---|---|
| Regression | 41.503 | 4 | 10.376 | 12.356 | < .001 |
| Residual | 45.345 | 54 | 0.840 | | |
| Total | 86.847 | 58 | | | |

**Table 8. Regression Coefficients for Operational Efficiency**

| **Model** | | **Unstandardized Coefficients** | | **Standardized Coefficients** | **t** | **Sig.** |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | -4.477 | 1.279 | | -3.502 | <.001 |
| | V32 | 1.096 | .314 | .374 | 3.490 | <.001 |
| | V33 | .380 | .304 | .140 | 1.252 | .216 |
| | V34 | 1.052 | .292 | .393 | 3.598 | <.001 |
| | V35 | -.097 | .246 | -.039 | -.392 | .697 |
| a. Dependent Variable: Operational Efficiency | | | | | | |

The model explained 47.8% of the variance (R2 = 0.478; Adjusted R2 = 0.439) and was statistically significant (F = 12.356, p < 0.001), according to the regression analysis done to evaluate the impact of the four independent factors on operational efficiency. The predictors that contributed most to operational efficiency were delivery and demand planning related improvements (V32) and tracking and delivery status related improvements (V34). Both had positive standardized coefficients (β = 0.374, p < 0.001; β = 0.393, p < 0.001, respectively). Improvements in last mile delivery (V33) had positive effect (β = 0.140) but the difference was not statistically significant (P = 0.216). Similarly, operational efficiency was found to have a negative but non-significant relationship with reliability and delivery quality related improvements (V35) (v = -0.039, p = 0.697).A similar finding is obtained in that operational efficiency in supply chain management is mostly determined by a strong delivery and demand planning approach coupled with effective tracking and monitoring systems; improvements in last-mile delivery and reliability factors do not significantly improve efficiency in this model. The model summary for Regression Model 2 is presented in Table 9. As shown in Table 10, the regression model was statistically significant, $F(4, 54) = 13.209$, $p < .001$, indicating that the predictors collectively explain a significant proportion of variance in sustainability outcomes. As shown in Table 11, last-mile delivery improvements (V33) and tracking-related improvements (V34) significantly predicted sustainability, whereas delivery and demand planning improvements (V32) did not.

**Table 9. Model Summary for Regression Analysis Predicting Sustainability in SCM**

| **Regression Model 2** | | | | |
|---|---|---|---|---|
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
| 1 | .703a | .495 | .457 | .647 |
| a. Predictors: (Constant), V35, V34, V32, V33 | | | | |

**Table 10. ANOVA Results for Regression Model Predicting Sustainability in SCM**

| **Source** | **SS** | **df** | **MS** | **F** | **p** |
|---|---|---|---|---|---|
| Regression | 22.113 | 4 | 5.528 | 13.209 | < .001 |
| Residual | 22.599 | 54 | 0.419 | | |
| Total | 44.712 | 58 | | | |

**Table 11. Regression Coefficients for Sustainability in SCM**

| **Predictor** | **B** | **SE** | **β** | **t** | **p** |
|---|---|---|---|---|---|
| Constant | -2.418 | 0.903 | — | -2.679 | .010 |
| V32 | 0.139 | 0.222 | .066 | 0.626 | .534 |
| V33 | 0.927 | 0.214 | .476 | 4.326 | < .001 |
| V34 | 0.626 | 0.206 | .326 | 3.032 | .004 |
| V35 | 0.037 | 0.174 | .021 | 0.211 | .034 |

*Note.* Dependent variable: Sustainability in SCM. Predictors: Delivery and demand planning improvements (V32), Last-mile delivery improvements (V33), Tracking and delivery status improvements (V34), and Reliability and delivery quality improvements (V35)

According to the Sustainability in SCM regression analysis, the model explained 49.5% of the variance in sustainability outcomes (R2 = 0.495; Adjusted $R^2$ = 0.457) and was statistically significant ($F = 13.209$, $p < 0.001$). Reliability and delivery quality improvements (V35) ($\beta = 0.021$, $p = 0.034$), tracking and delivery status related improvements (V34) ($\beta = 0.326$, $p = 0.004$), and last-mile delivery improvements (V33) ($\beta = 0.476$, $p < 0.001$) were found to have a significant positive impact on supply chain management sustainability. Improvements related to demand planning and delivery (V32) ($\beta = 0.066$, $p = 0.534$) did not, however, show a significant impact. These findings indicate that sustainability in SCM is largely strengthened by enhancing last-mile delivery processes, improving tracking and monitoring mechanisms, and ensuring delivery reliability and quality, while demand planning improvements play a minimal role in achieving sustainability outcomes.

## 4. RESULTS AND FINDINGS

The robustness of the measurement scale was tested for reliability on all the thirty-two variables considered in the study. The Cronbach-Alpha value was 0.788 which is very much greater than the minimum value of 0.70 which is generally accepted. This demonstrates that the scale has a high internal consistency, in that the variables chosen provide appropriate measures of the constructs that they are designed to measure. The results suggest that the data is reliable enough to use sophisticated statistical analyses such as factor analysis and regression. Exploratory Factor Analysis was conducted to identify the important issues for logistics professionals regarding digital transformation and innovation in supply chain management. The sampling adequacy (KMO measure) was measured at 0.772, which showed that the data was adequate for the factor analysis. Also, Bartlett's Test of Sphericity was found to be significant ($\chi^2 = 2344.512$, $df = 642$, $p < 0.001$), thus supporting enough correlations among variables to go for factor extraction. Based on latent root criterion, four factors with Eigen values greater than one were extracted. Together, these factors explained 41.572 percent of the total variance, with the first factor explaining 12.655 percent of the variance. The four identified factors were categorised as delivery and demand planning related improvements, last-mile delivery related improvements, tracking and delivery status related improvements and reliability and delivery quality related improvements. These findings imply that technological advancements in supply chains are evaluated by customers in four major dimensions that capture both effectiveness of operations and quality of services. The purpose of this study was to examine how the four independent factors delivery and demand planning related improvements (V32), last-mile delivery related improvements (V33), tracking and delivery status related improvements (V34), and reliability and delivery quality related improvements (V35) influence two key dependent variables in supply chain management: operational efficiency and sustainability. The results of two regression models are presented in this section. From a JAES perspective, these relationships explain how technology adoption supports sustainable entrepreneurship by improving customer value and sustainability performance under SME resource constraints.

The first model explains the effect of the factors on operational efficiency. The regression model is statistically significant at the 0.001 level (F=12.356) and explains 47.8% of the variance of operational efficiency ($R^2$=0.478; Adjusted $R^2$= 0.439). This means the independent variables, interacting with each other, have a fairly high explanatory power toward performance as regarded in supply chain processes. Among predictors, delivery and demand planning improvements (V32) and tracking and delivery status improvements (V34) entered as significant predictors, with standardized beta coefficients of 0.374 ($p < 0.001$) and 0.393 ($p < 0.001$), respectively. These implications highlight that operational efficiency is primarily ensured through good demand planning mechanisms and competent tracking systems, which together reduce inefficiencies, assist in scheduling, and provide greater visibility in the supply chain. Conversely, last-mile delivery improvements (V33) showed a positive but non-significant impact of 0.140 at $p = 0.216$, telling us that such improvements may assist the cause but may not directly bolster efficiency. The same applies to reliability and delivery quality. The second model investigated the influence of the factors on sustainability in supply chain management. The results revealed that the regression model was also statistically significant ($F = 13.209$, $p < 0.001$), explaining 49.5% of the variance in sustainability outcomes ($R^2 = 0.495$; Adjusted $R^2 = 0.457$). Compared to the first model, this shows a slightly higher explanatory power, suggesting that these factors are even more relevant when assessing sustainability. Three predictors were found to have significant positive effects on sustainability. Last-mile delivery improvements (V33) had the strongest impact ($\beta = 0.476$, $p < 0.001$), highlighting that sustainable outcomes in SCM are greatly enhanced by optimising last-mile delivery processes, such as through eco-friendly transportation methods and efficient route planning. Tracking and delivery status improvements (V34) also contributed significantly ($\beta = 0.326$, $p = 0.004$), reinforcing the importance of visibility and monitoring in minimising resource waste and ensuring responsible supply chain practices. Reliability and delivery quality improvements (V35) further showed a small but significant positive influence ($\beta = 0.021$, $p = 0.034$), suggesting that ensuring consistent and reliable delivery performance supports long-term sustainability goals. However, delivery and demand planning improvements (V32) were not statistically significant ($\beta = 0.066$, $p = 0.534$), implying that while planning is vital for efficiency, its direct impact on sustainability outcomes is limited. The comparative standardized beta coefficients for both regression models are illustrated in Figure 2. The comparative model fit statistics are presented in Figure 3.

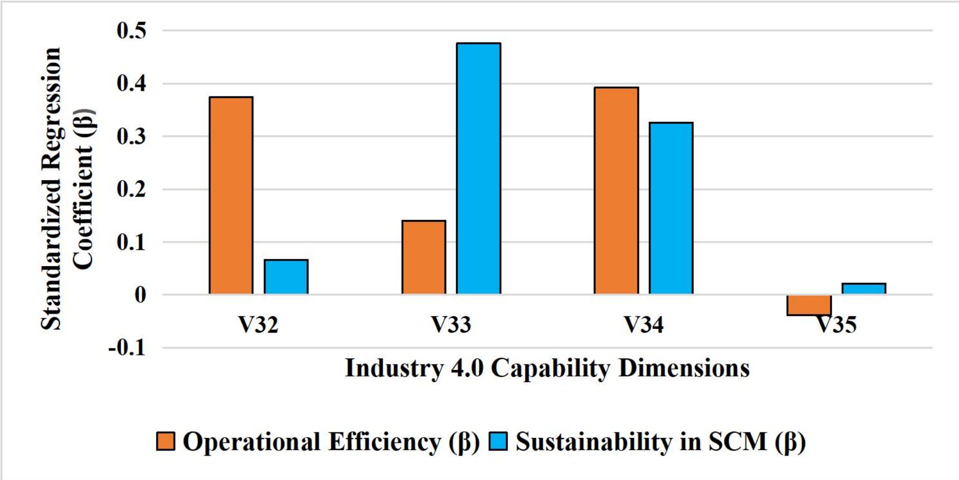


**Figure 2. Comparative Effects of Industry 4.0 Capability Dimensions on Operational Efficiency and Sustainability**

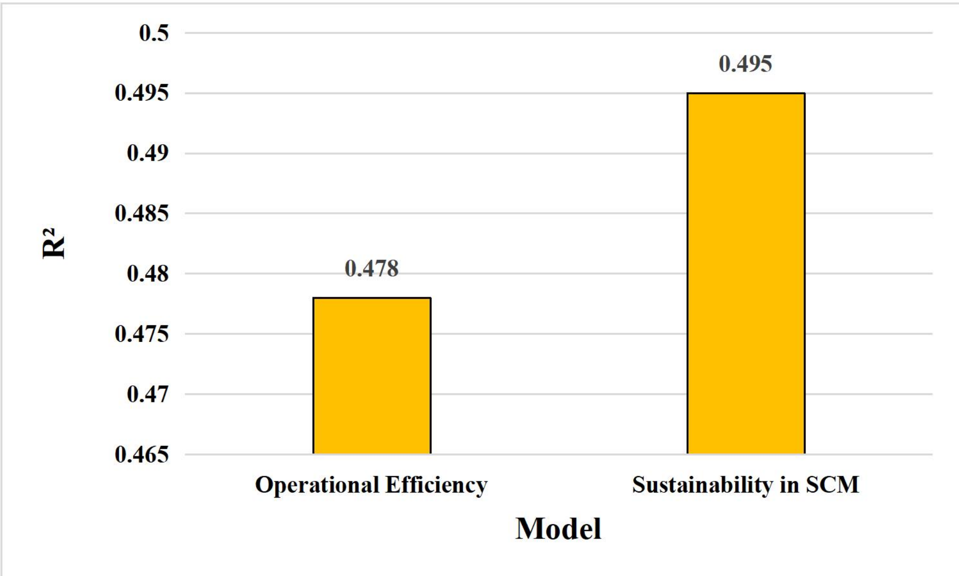


**Figure 3. Model Fit ($R^2$) Comparison**

The visual comparison presented in Figures 2 and 3 strengthens the findings of the regression analyses by emphasising the difference between the influence of the Industry 4.0 capability dimensions on performance outcomes. While delivery planning and tracking improvements show stronger impacts on operational efficiency, last mile delivery and tracking capabilities seem to have a stronger impact on sustainability when it comes to supply chain management. Additionally, the similar R2 values point to the fact that both models offer significant explanatory power vindicating the relevance of digital transformation capabilities in improving e-retail supply chain performance.

## 5. DISCUSSION

The results of this study give empirical support to the increased relevance of Quality 4.0 in supply chain management, especially in the context of digital transformation and sustainable logistics. The use of state-of-the-art tech like Artificial Intelligence, Machine Learning, Internet of Things (IoT) and Big Data is proving to have measurable impact on a company's operational efficiency as well as its sustainability performance. This is consistent with previous studies that highlight the importance of digital technologies in improving the accuracy of forecasts, optimising routes, and decision-making processes in logistics systems (Boute & Udenio, 2021; Badrinarayanan, 2024). The results strengthen the argument that digital innovation is no longer a tool for mere upgrading of technology but a strategic mechanism for better supply chain results (Wang et al., 2016).

The first regression model showed that the effectiveness of operational efficiency is significantly considered by delivery and demand planning improvement and tracking and delivery status-related improvements. These findings are consistent with the works of Christopher (2016), who stressed on the critical role of structured planning as well as visibility in achieving supply chain efficiency. Real-time monitoring and predictive analytics help in reducing delays, scheduling accuracy, and coordination across logistics networks (Badrinarayanan, 2024; Wang et al., 2016). The intense effect of tracking and monitoring proves that visibility technologies like IoT based technology brings great help in decreasing inefficiencies and improving performance reliability.

Interestingly, last mile delivery improvements did not have a substantial impact on operational efficiency even though there are studies in the existing literature that identify last mile logistics as one of the most expensive and complex segments of the supply chain (Bosona, 2020). While last-mile operations may contribute quite a big percentage of total logistics costs - sometimes up to 28% (Bosona, 2020) - the findings suggest that isolated last-mile interventions may not directly improve efficiency unless supported by effective demand planning and integrated monitoring systems. This suggests that systemic coordination may be more important to efficiency outcomes than are local delivery interventions. Similarly, improvements in reliability and quality of delivery did not have a strong impact on operational efficiency. This implies that efficiency is more about process levels of optimization rather than customer-facing service attributes.

The second regression model allows to get a better insight into sustainability outcomes. Sustainability in supply chain management was significantly affected by the improvement in the last mile, improvement of tracking and delivery status, reliability and improvement of delivery quality. The most important predictor was improvements in the last mile of delivery, which reinforces the findings of other studies showing the environmental importance of optimising urban delivery systems (Marchet et al., 2014). The use of eco-friendly vehicles, optimised routing systems and alternative delivery mechanisms have been recognised widely as essential for reduction of emissions and energy efficiency (Dube et al. 2011; Bosona, 2020). The results validate the fact that the sustainability performance is deeply related to the operational practises in the last stage of the delivery.

Tracking and monitoring technologies also displayed a significant positive effect on sustainability, which is consistent with research research that indicated that IoT-enabled visibility led to the reduction of fuel consumption, minimisation of resource wastage, and improved environmental performance (Salam et al., 2024; Wang et al., 2016). Real-time data means organisations will be able to spot inefficiencies and optimise delivery processes, which will have a direct impact on greener logistics operations. In contrast, improvements in delivery and demand planning did not affect sustainability outcomes to any significant extent. This supports the idea that while planning systems increases efficiency (Christopher, 2016), sustainability is more directly affected by implementation level operational practises in the last-mile execution (Marchet et al., 2014).

When you compare both regression models, it is clear that there are clear differences between drivers of operational efficiency and sustainability. Efficiency is dominated by the upstream coordination mechanisms (demand planning and digital visibility systems) while sustainability is more dependent on downstream delivery practises, route optimisation and environmentally responsible transportation strategies. This distinction is a result of an evolving understanding in the supply chain literature that operational efficiency and sustainability are, while linked, affected by different structural and technological mechanisms (Jawali, 2024; Marchet et al., 2014).

Overall, the results extend existing literature by empirically demonstrating that Quality 4.0 technologies influence supply chain performance through differentiated pathways. Planning and visibility mechanisms primarily enhance internal process efficiency (Christopher, 2016; Badrinarayanan, 2024), while last-mile optimization and green logistics practices drive environmental sustainability outcomes (Dube et al., 2011; Bosona, 2020). The integration of AI, IoT, and analytics therefore supports a dual-performance model in which digital transformation simultaneously strengthens operational resilience and environmental responsibility (Boute & Udenio, 2021; Wang et al., 2016).

The factor analysis revealed some key aspects of supply chain performance especially delivery and demand planning, tracking and delivery status, last-mile delivery, and delivery reliability. For managers, it means that these areas are the most important levers for performance, and should be prioritised on a strategic basis. By homing in on these factors, companies can streamline their planning processes, build visibility, and improve customer service all essential for building resilient and responsive supply chains. The results from the regression analysis also provided further evidence of the practical importance of these elements. It was found that operational efficiency is greatly affected by delivery and demand planning, and improvements in tracking and monitoring. This suggests that managers should consider investing in advanced forecasting, data-driven planning, and real-time monitoring systems to minimize delays and optimize resource allocation. On the flip side, sustainability outcomes were largely driven by last mile delivery, as well as tracking systems and the quality of reliable deliveries. Therefore, managers must pay attention to greener last-mile operations, such as route optimization and electric vehicles, as well as making sure that the deliveries are accurate and reliable in order to reduce waste and environmental impact. Altogether, these findings provide a clear direction for retailers. For policymakers and ecosystem actors working in Asia, results imply supporting access of SMEs to digital infrastructure, EV charging networks and guidelines on responsible innovation (CSR/ethics) for speeding up green and inclusive enterprise growth.

Due to the wide differences in institutional conditions across Asian economies, the results may differ across countries depending on logistical infrastructure maturity and policy support for green delivery. Like any empirical study, this research is accompanied by its share of limitations that we should bear in mind when making sense of the results. For starters, the data targeted only thirty-two variables and two dependent constructs, which were operational efficiency and sustainability in supply chain management. While this approach provided some valuable insights, it didn't consider other important aspects of performance such as cost-effectiveness, customer loyalty, or resiliency, which also could be impacted by advancements in technology for logistics. Future research could widen the scope by adding more dependent variables to obtain a more well-rounded understanding of the effect of technology on the performance of supply chain. Additionally, the study was conducted using factor analysis and regression models to examine the relationship between variables. Although these methods are effective for spotting associations, they don't prove causation.

## 6. CONCLUSION

This study investigated the effects of the adoption of Industry 4.0 (Quality 4.0) on operational efficiency and sustainability in the last-mile supply chain management for the e-retail sector. Using factor analysis and regression models, the results show that digital transformation affects supply chain performance through both different and interrelated mechanisms. The results show that the primary motivation behind the operational efficiency has been through improvements in delivery and demand planning and through improvements in tracking and monitoring systems. These dimensions provide greater coordination, reduce delays and increase visibility across logistics networks. In contrast, sustainability performance is considerably affected by improvements in last mile delivery, tracking systems and delivery reliability. The greatest effect was found for last mile delivery improvements, which suggests that there is a close relationship between environmental sustainability and operational practises at the final stage of delivery. One of the key aspects that this study contributes is the identification of differentiated drivers for efficiency and sustainability. While both outcomes are made efficient through digital technologies, efficiency is influenced more by upstream planning and coordination mechanisms, while sustainability relies more on downstream delivery execution and environmentally responsible logistics practices. This distinction moves the understanding of how Quality 4.0 technologies apply in supply chain systems forwards as well as the importance of having balanced investments in planning, visibility and last-mile innovation. The findings add to the growing literature on digital transformation and sustainable supply chain management by adding empirical evidence to the fact that Industry 4.0 technologies support dual performance objectives. For practitioners, the results suggest organisations that want to achieve operational excellence should focus on data-driven planning and real-time monitoring systems; and those that want to achieve sustainability goals should focus on green last-mile strategies and delivery reliability mechanisms. Overall, the study strengthens the strategic importance of the integration of advanced digital technologies in supply chain operations to obtain both efficiency and sustainability. As the markets for e-retail are still growing and the pressure on the environment is rising, the role of Quality 4.0 technologies will become more and more central to creating resilient, responsible and performance-oriented logistics systems.

## REFERENCES

1. Alkhodair, M., & Alkhudhayr, H. (2025). Harnessing industry 4.0 for SMEs: Advancing smart manufacturing and logistics for sustainable supply chains. *Sustainability*, *17*(3), 813.
2. Badrinarayanan, A. (2024). AI-Driven Optimization of Last-Mile Delivery. *International Journal For Multidisciplinary Research*, 6(6). https://doi.org/10.36948/ijfmr.2024.v06i06.32057
3. Beck, K., Esquillor, J., Zarei, M. M., Froes, I., Hauswald, I., Giannakopoulou, A., & Flämig, H. (2025). Making last mile logistics models aware of customer choices, demand sustainability and data economy. *European Transport Research Review*, *17*(1), 29.
4. Bosona, T. (2020). Urban Freight Last Mile Logistics—Challenges and Opportunities to Improve Sustainability: A Literature Review. *Sustainability*, 12(21), 8769. https://doi.org/10.3390/su12218769
5. Bousdekis, A., Lepenioti, K., Apostolou, D., & Mentzas, G. (2023). Data analytics in quality 4.0: literature review and future research directions. *International Journal of Computer Integrated Manufacturing*, *36*(5), 678-701.
6. Boute, R., & Udenio, M. (2021). AI in Logistics and Supply Chain Management. *Social Science Research Network*. https://doi.org/10.2139/SSRN.3862541

7. Bucha, Sahil. (2021). Optimisation Of Last-Mile Delivery In E- Commerce Logistics. *International Journal of Information and Electronics Engineering*, 11, 36–45. https://doi.org/10.18178/ijiee.2021.11.4.6
8. Buldeo Rai, H., & Dablanc, L. (2023). Hunting for treasure: a systematic literature review on urban logistics and e-commerce data. *Transport Reviews*, *43*(2), 204-233.
9. Christopher, M. (2016). *Logistics & supply chain management* (5th ed.). Pearson Education.
10. Di Nardo, M., Gallab, M., Murino, T., Wu, J., & Pandey, S. (2025). Integrating sustainability and industry 4.0: A framework for sustainable logistics 4.0. *Circular Economy and Sustainability*, *5*(3), 2157-2195.
11. Dube, A., Gawande, R. R., & Coe, D. B. (2011). Green Supply Chain management–A literature review. *International Journal of Computer Applications*, *975*, 8887.
12. Fried, T., & Goodchild, A. (2023). E-commerce and logistics sprawl: A spatial exploration of last-mile logistics platforms. *Journal of Transport Geography*, *112*, 103692.
13. Gonzalez, J. N., Garrido, L., & Vassallo, J. M. (2023). Exploring stakeholders' perspectives to improve the sustainability of last mile logistics for e-commerce in urban areas. *Research in Transportation Business & Management*, *49*, 101005.
14. Idrissi, Z. K., Lachgar, M., & Hrimech, H. (2024). Blockchain, IoT and AI in logistics and transportation: A systematic review. *Transport Economics and Management*, *2*, 275-285.
15. Jacay-Aldui, et al. (2022). Industry 4.0 and last mile logistics: New challenges and approaches – A bibliometric review. *Proceedings of the 3rd Asia Pacific International Conference on Industrial Engineering and Operations Management*, Johor Bahru, Malaysia, September 13–15, 2022.
16. Jawali, R. R., & Ramya, S. (2024). A study on challenges and optimization of last mile delivery and its impact on customer satisfaction. *Inter. J. Multidisciplinary Res*, *6*(4), 1-9.
17. Marchet, G., Melacini, M., & Perotti, S. (2014). Environmental sustainability in logistics and freight transportation: A literature review and research agenda. *Journal of Manufacturing Technology Management*, *25*(6), 775-811.
18. Nagadeepa, C., Dyczek, B., Mishra, A. K., Valerii, B., Oleksandr, O., & Sokoliuk, K. (2024). Last-mile delivery innovations: The future of e-commerce logistics. In *Technology-Driven Business Innovation: Unleashing the Digital Advantage, Volume 1* (pp. 283-296). Cham: Springer Nature Switzerland.
19. Nogueira, G. P. M., Silva, S. V., Hasenclever, L., & de Assis Rangel, J. J. (2025). Sustainability in B2C e-commerce: a literature review and future research opportunities in last-mile deliveries. *Environment, Development and Sustainability*, *27*(6), 12415-12436.
20. Qureshi, K. M., Mewada, B. G., Kaur, S., Khan, A., Al-Qahtani, M. M., & Qureshi, M. R. N. M. (2024). Investigating industry 4.0 technologies in logistics 4.0 usage towards sustainable manufacturing supply chain. *Heliyon*, *10*(10).
21. Rai, H. B., Broekaert, C., Verlinde, S., & Macharis, C. (2021). Sharing is caring: How non-financial incentives drive sustainable e-commerce delivery. *Transportation Research Part D: Transport and Environment*, *93*, 102794
22. Saidi, A., & Ayadi, N. (2025). Enhancing Logistics Efficiency: A Comprehensive Study of Royal Solidex company. IJRDO - *Journal of Business Management.* https://doi.org/10.53555/bm. v11i1.6217
23. Salam, A. A., Widjanarko, W., & Sumantyo, F. D. S. (2024). Analisis Pengaruh Kecepatan, Akurasi, dan Biaya Pengiriman terhadap Kepuasan Pelanggan: Studi Kasus CV Konita Agro Putra. *Journal of Islamic Economics and Finance*, *2*(3), 283-297.
24. Tran, T. P. A., & Gavade, S. A. (2025). Evaluating sustainable last mile delivery solutions: A multi-criteria decision analysis. *Journal of Supply Chain Management Science*, *6*(1-2).
25. Wang, G., Gunasekaran, A., Ngai, E. W., & Papadopoulos, T. (2016). Big data analytics in logistics and supply chain management: Certain investigations for research and applic ations. *International journal of production economics*, *176*, 98-110.