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Sustainable Digital Transformation in Logistics: A Regression Modeling Approach to Logistics 4.0 Awareness

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ABSTRACT

The ever increasing digital transformation in the logistics sector contributes to sustainable development goals. This study investigated the awareness levels of Logistics 4.0 among companies operating in national and international markets, members of the International Association of Transport and Logistics Service Providers (UTIKAD). Data were collected using a survey developed in 2020 (Çiçekli, 2020). The survey was distributed to the firms via email, and statistical analyses were performed using the responses received from 110 companies. All statistical procedures were carried out using the SPSS 25.0 software package. After confirming that the dataset was suitable for factor analysis, a Principal Component Analysis (PCA) was conducted. Four factors were identified: economic benefit, firm structure, digital technology usage, and awareness. To determine the variables that influence firms' awareness of Logistics 4.0, a multiple linear regression analysis was performed. The results revealed that the most significant predictors of Logistics 4.0 awareness were the economic benefit and digital technology usage variables.

Keywords: Logistics 4.0, Digital Transformation, Smart Logistics, Cloud Logistics, Internet of Things, Tracking and Tracing
JEL Classifications: L91, O33, M15, C38

1. INTRODUCTION

Sustainability has begun to impact long term competitiveness in nearly every major industry, including energy, agriculture, manufacturing, logistics, and services (Dyllick and Muff, 2015). Sustainability is no longer viewed solely as an environmental responsibility for companies. Sustainability practices are now being integrated into decision making processes. It aims to reduce ecological impacts, use resources more efficiently, and create greater value for customers, employees, and society (Lozano, 2013). Environmental sustainability includes issues such as using renewable energy sources, reducing water consumption, and using sustainable raw materials. At the societal level (Social) sustainability fosters the development of people, communities, and cultures to contribute to the reasonable and equitable distribution of quality of life, healthcare, and education worldwide, while at the economic level, sustainability focuses on equitable economic growth that creates wealth for all without harming the environment (Stroumpoulis et al., 2024). The core components of Industry 4.0 include robotics, automation, big data, simulation, system integration, the Internet of Things (IoT), cybersecurity, cloud systems, additive manufacturing, and augmented reality. These digital technologies increase companies' production speed, reduce costs, improve quality, and enhance operational flexibility (Jagtap et al., 2020; Dixit and Verma, 2024). Industry 4.0 also enables companies to cope with increasing competitive pressures and adapt to rapidly changing market conditions. Industry 4.0 is an important concept in improving the market performance of businesses. The digitalization brought about by Industry 4.0 creates more efficient and customer focused supply chains (Ahmed et al., 2021).

Industry 4.0 components (autonomous vehicles, IoT, RFID, AR, 3D printing) play a significant role in supply chain management by improving warehouse operations (Fidlerova et al., 2025; Faisal et al., 2019; Madakam et al., 2015; Sharma et al., 2020; Winkelhaus and Grosse, 2019; Moeinfar et al., 2012; Oncioiu et al., 2025;

Epe et al., 2024; Chan et al., 2018). These technologies support sustainability efforts while boosting operational efficiency. As firms embed sustainability across their processes, supply chain management becomes a central area for advancing responsible production. From this perspective, the value of Industry 4.0 technologies is increasingly clear (Helo and Thai, 2024; Feng et al., 2025; Chauhan et al., 2023).

1.1.Theoretical Framework

This study is founded on the Technology-Organization-Environment (TOE) framework (Tornatzky and Fleischer, 1990). In this framework, the technological context refers to the availability, quality, and usefulness of new technologies, while the organizational context includes companies' internal resources, managerial attitudes, and operational capabilities. The environmental context encompasses pressures from competitors, regulations, customers, and sustainability expectations. Raising firms' awareness of Logistics 4.0 is particularly aligned with SDG 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production). Both sustainable development goals include effi-cient resource use, innovation driven growth, and the responsible transformation of production and logistics systems.

2. MATERIALS AND METHODS

This study was conducted with member companies of the International Transport and Logistics Service Providers Association (UTİKAD), one of the leading organizations in the Turkish logistics sector. UTİKAD represents a significant portion of Turkey's logistics and transportation companies, as well as companies operating internationally. Therefore, it was chosen for this study. The survey developed by Çiçekli (2020) was emailed to all UTİKAD member companies, and survey data from 110 companies were included in the analysis. All statistical analyses were conducted using SPSS 25.0. First, the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity were applied to assess the suitability of the resulting data set for factor analysis. After verifying data adequacy, principal component analysis (PCA) was conducted, and Cronbach's alpha coefficients were calculated to assess the internal consistency of the resulting subfactors. Following the factor analysis, multiple linear regression was performed to identify the variables that most strongly influenced companies' Logistics 4.0 awareness. Before estimating the regression model, standard assumptions such as normality, linearity, homoscedasticity, and multicollinearity were examined. The resulting multiple linear regression model identified the factors influencing Logistics 4.0 awareness.

2.1. Research Hypotheses

- H_1: The scale items used in the study form a meaningful structure representing the concept intended to be measured.
- H_2: There is a correlation between the scale items at a level that supports a common structure.

This study aims to explore the factor structure of the scale. Additional hypotheses will be written after the factor structure is determined.

3. RESULTS

Before proceeding with the factor analysis, the dataset was evaluated to ensure that it met the necessary statistical conditions. To assess whether the data set was suitable for factor analysis, KMO and Bartlett's test of sphericity were performed and the results are given in Table 1.

H_1: The scale items used in the study constitute a meaningful structure representing the intended concept.

The KMO value of 0.747 was found to be suitable for factor analysis with a sample size of 0.747. Bartlett's test tests the relationship between variables. The test result shows (sig. < 0.001), which confirms H1. A significant relationship exists between the variables, and factor analysis is feasible. After determining the suitability of the scale items, PCA analysis was conducted, and the results are presented in Table 2.

As seen in Table 2, the factor analysis yielded four distinct factors with eigenvalues above 1. These four factors accounted for 58.4% of the total variance. After applying Varimax rotation, the factor loadings are shown in Table 3. The analysis was conducted using principal component analysis as the extraction method, followed by Varimax rotation with Kaiser normalization.

As seen in Table 3, four factors were identified as a result of the factor analysis.

- Factor 1 – Economic benefit: This factor includes opinions about efficiency improvements, profitability and system integration, investment costs, and long term financial returns.
- Factor 2 – Company structure: This factor includes structural characteristics of companies such as their core business areas, service categories, transportation methods, and workforce size.
- Factor 3 – Digital technology: This factor encompasses variables related to the use or potential use of tracking systems, digital tools, and automation technologies.
- Factor 4 – Awareness: Items under this factor relate to companies' knowledge levels, participation in R&D activities, expectations regarding inventory cost reductions, and expected changes in workforce dynamics.

3.1. Additional Hypotheses Established after the Factor Analysis are as Follows

- H_3: Perceived economic benefit positively and significantly affects companies' awareness of Logistics 4.0.

Table 1: KMO and Bartlett's test of sphericity

Test	Statistic	Value
Kaiser–Meyer–Olkin measure of sampling adequacy		0.747
Bartlett's test of sphericity	Approx. χ^2 (153)	718.587
	Sig.	P<0.001

Table 2: Total variance explained by extracted components

Component	Eigen value	% of Variance	Cumulative %
1	4.627	25.703	25.703
2	2.861	15.892	41.595
3	1.887	10.485	52.081
4	1.138	6.324	58.404

Table 3: Rotated component matrix (varimax rotation)

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Number of employees in the firm		0.611		
I have advanced knowledge about Logistics 4.0.				0.661
The firm conducts activities related to Logistics 4.0 (R&D, investment, etc.).				0.461
Logistics 4.0 will reduce inventory costs				0.758
Logistics 4.0 will accelerate logistics processes, increasing efficiency and profitability.	0.548			
The investment cost of intelligent, autonomous, and digital technologies in Logistics 4.0 is high	–0.679			
If the firm invests in Logistics 4.0, it will be profitable in the long run	0.681			
The use of labor in freight transportation will decrease with Logistics 4.0				0.731
The number of technologically skilled employees in the logistics sector will increase with Logistics 4.0	0.523			
Integrated systems compatible with customers and suppliers should be used for Logistics 4.0	0.760			
Firms' individual efforts are not sufficient for adapting to Logistics 4.0	–0.627			
The commercial activities performed by the firm		0.754		
The sector (s) to which logistics services are provided		0.829		
The mode (s) of transportation used		0.830		
Tracking/monitoring system (s) used in the firm			0.698	
Digital technology application (s) used in the firm			0.757	
Area (s) where automation and digital technologies are considered beneficial			0.692	
Digital application (s) considered potentially usable			0.759	

*Factor 1: Economic benefit, Factor 2: Firm structure, Factor 3: Digital technology, Factor 4: Awareness

- H_4: Company structure positively and significantly affects companies' awareness of Logistics 4.0.
- H_5: Digital technology use positively and significantly impacts companies' awareness of Logistics 4.0.

Reliability analysis results are presented in Table 4. Cronbach's alpha values for the subdimensions (factors) were found to be at acceptable levels. These findings can be interpreted as indicating that the subdimensions consistently and consistently measure Logistics 4.0 awareness and adoption.

The basic assumptions of multiple linear regression analysis (normality, linearity, homoscedasticity, and multicollinearity) were tested. The points on the P-P Plot also aligned closely with the 45° reference line, indicating that the error terms followed an approximately normal distribution (Figure 1).

Linearity and homoscedasticity were examined using a scatter plot comparing standardized residuals with predicted values (Figure 2). Inspection of the plot revealed that the data points were randomly distributed along the horizontal axis and that there was no clustering. These observations indicate that both assumptions were adequately met.

Multicollinearity was assessed using the collinearity diagnostics procedure. when examining the condition index values, the highest value was measured as 20.425, indicating that the model did not suffer from multicollinearity. Overall, these findings indicate that the predictor variables operate independently of each other and that the regression coefficients can be estimated with confidence (Table 5).

Assumption checks demonstrated that the regression model is statistically robust and can be used with confidence. A model summary table resulting from the regression analysis is provided in Table 6.

The model summary results indicate that economic benefits and digital technology use play a significant role in explaining firms'

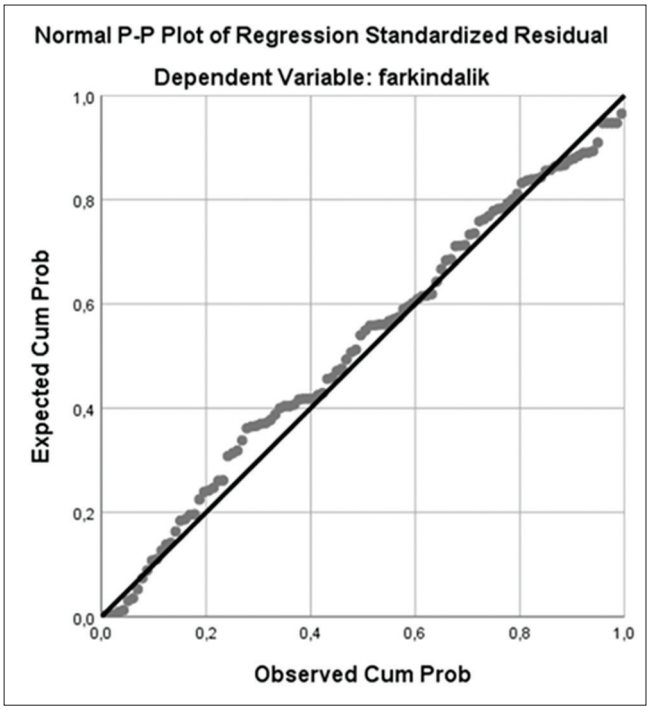
Table 4: Reliability analysis results

Factor	Number of ıtems	Cronbach's alpha
Economic benefit	6	0.773
Firm structure	4	0.577
Digital technology	4	0.704
Awareness	5	0.772

Table 5: Collinearity diagnostics results

Model dimension	Eigen value	Condition index	Variance proportions		
			Constant	Digital technology	Economic benefit
1	2.868	1.000	0.00	0.02	0.00
2	0.125	4.796	0.02	0.98	0.02
3	0.007	20.425	0.98	0.00	0.98

Figure 1: Normal P–P plot (residuals)



awareness levels (Table 6). The coefficient of determination ($R^2 = 0.311$) means that these two variables explain approximately 31.1% of the variation in awareness. The adjusted R^2 value (0.298) supports the model's stability considering the sample size. All these results taken together indicate that the model performs reliably and is suitable for interpreting the relationships between variables. The ANOVA table obtained from the regression analysis is presented in Table 7.

An examination of the ANOVA results obtained from the regression analysis reveals that the model is statistically significant ($P < 0.001$) (Table 7). When firm structure was used as the independent variable in the regression analysis, its effect on the model was found to be statistically insignificant, and therefore, it was not included in the model. It is thought that company structure may have a secondary effect on Logistics 4.0 awareness. This result indicates that economic benefits and digital technology use together largely explain the change in companies' Logistics 4.0 awareness levels. The regression coefficients table is given in Table 8.

Figure 2: Scatter plot (standardized residuals vs. predicted values)

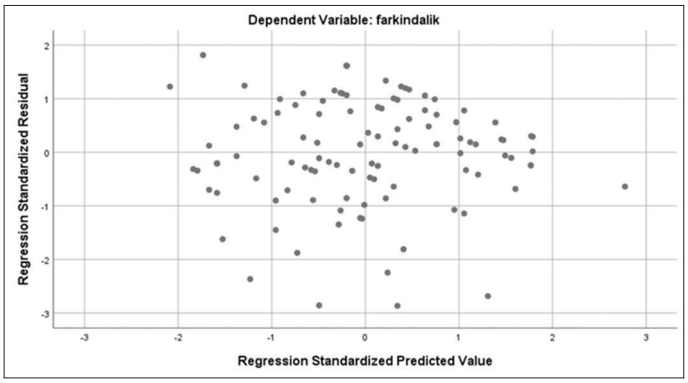


Table 6: Model summary for multiple linear regression

Model	R	R Square	Adjusted R square	Standard error of the estimate
1	0.558	0.311	0.298	0.72832

*Dependent variable: Awareness, Predictors: Economic benefit, digital technology

Table 7: ANOVA results for multiple linear regression model

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	25.658	2	12.829	24.185	0.000
Residual	56.758	107	0.530		
Total	82.416	109			

*Dependent variable: Awareness, Predictors: Economic benefit, digital technology

Table 8: Coefficients of the multiple linear regression model

Predictor	Unstandardized coefficients (B)	Standard error	Standardized coefficients (Beta)	t	Sig. (P)
(Constant)	0.382	0.596	–	0.640	0.524
Economic benefit	0.855	0.174	0.398	4.906	0.000
Digital technology	1.624	0.389	0.338	4.172	0.000

An examination of the regression coefficients reveals that the economic benefit variable and digital technology use have a positive and statistically significant impact on firms' awareness of Logistics 4.0. These results suggest that firms become more aware of Logistics 4.0 as they perceive stronger economic advantages and utilize digital technologies more. Looking at the details of the model established based on the regression results, a one unit increase in perceived economic benefit by companies results in an increase of approximately 0.855 units in awareness. A one unit increase in the digital technology usage variable results in an increase of approximately 1.624 units in the Logistics 4.0 awareness score. The estimated regression equation is:

$$\text{Awareness} = 0.382 + 0.855\ (\text{Economic Benefit}) + 1.624\ (\text{Digital Technology}) \quad (1)$$

4. CONCLUSION

This study was conducted with member firms of the Association of International Forwarding and Logistics Service Providers (UTIKAD). This empirical study examines firms' awareness of Logistics 4.0 and their digital transformation, providing interesting results on sustainability. This study has demonstrated with empirical evidence that technological readiness driven by the use of digital technology and corporate motivation reflected in perceived economic benefits shape firms' Logistics 4.0 awareness together and expanded the Technology-Organization-Environment (TOE) framework.

Awareness of Logistics 4.0 was examined among Turkish logistics companies operating internationally and nationally. Factor analysis revealed four distinct dimensions: Economic benefit, firm structure, digital technology, and logistics 4.0 Awareness Level.

Regression findings indicated that perceived economic benefits positively impacted companies' awareness of Logistics 4.0. Companies that believe that the use of digital technologies will reduce costs and increase efficiency tend to have a stronger understanding of Logistics 4.0. This study concluded that companies using digital technologies have higher awareness and adoption levels of Logistics 4.0. This result is consistent with previous studies (Winkelhaus and Grosse, 2020; Yu and Chiou, 2022). Digital transformation is closely related to the sustainability goals of Logistics 4.0 (Oncioiu et al., 2025; Vicente et al., 2024). Increasing awareness of Logistics 4.0 contributes to Sustainable Development Goals 9 (Industry, Innovation, and Infrastructure) and Sustainable Development Goals 12 (Responsible Consumption and Production).

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