

The Influence of Load Imbalance, Market Structure Distortion, and Logistics Digitalization as Determinants of Truck Transportation Costs Through Supply Chain Collaboration: Empirical Evidence From the Logistics Industry in Indonesia

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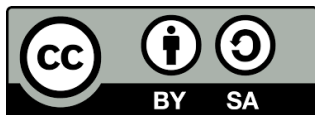
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Abstract

The logistics transportation sector plays a critical role in supporting economic activities; however, the trucking industry in Indonesia continues to face challenges related to high transportation costs caused by load imbalance, market structure distortion, limited digital integration, and weak supply chain coordination. This study aimed to analyze the influence of load imbalance, market structure distortion, and logistics digitalization on truck transportation costs through supply chain collaboration as a mediating variable in the Indonesian logistics industry. The research employed a quantitative approach with an explanatory research design using a cross-sectional method. Data were collected from 203 respondents involved in distribution and transportation activities at PT Putera Sarana Usaha (PSU Expedisi) using purposive sampling. The data were analyzed using Structural Equation Modeling–Partial Least Squares (SEM–PLS). The findings indicated that logistics digitalization, market structure distortion, load imbalance, and supply chain collaboration significantly influenced truck transportation costs. Logistics digitalization demonstrated the strongest effect on supply chain collaboration ($\beta = 0.844$), while supply chain collaboration contributed to reducing load imbalance and improving transportation efficiency. The structural model demonstrated strong predictive capability, with an R^2 value of 0.737 for truck transportation costs. This study implies that improving trucking efficiency requires integrated digital transformation, stronger collaboration among supply chain actors, reduction of empty backhaul movements, and the development of a more transparent and competitive logistics market structure.



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INTRODUCTION

The logistics sector plays a strategic role in supporting national economic activities because it serves as a primary link between production, distribution, and consumption processes (Biraimah et al., 2024; Major, 2025; Miskinzod, 2023). Syafrianita et al. (2025) explained that effective logistics distribution influences supply chain continuity, supply stability, and national economic competitiveness. Within Indonesia's logistics system, trucking transportation continues to dominate domestic distribution due to its flexibility in reaching industrial areas, ports, distribution centers, and end consumers. Purnomo et al. (2023) emphasized that the dominance of trucking makes transportation efficiency an important factor influencing national logistics costs and company distribution performance.

Despite its central role in national distribution, Indonesia's trucking industry continues to face various operational and structural challenges that contribute to high transportation costs (Aditya et al., 2026; Amin et al., 2024; Anas et al., 2022; Humang et al., 2025; Lanori & Supriyanto, 2023; Sinaga et al., 2022). Syafrianita et al. (2024) explained that high distribution costs are influenced by limited distribution integration, weak logistics visibility, and suboptimal utilization of digital technology. One of the major challenges is load imbalance (empty backhaul), which occurs when vehicles return without cargo after completing delivery activities. Purnomo et al. (2023) explained that empty backhaul reduces fleet utilization, increases fuel consumption, and raises distribution costs per trip. Mustafia et al. (2023) further emphasized that empty fleet movements cause companies to continue bearing operational costs without generating revenue during return trips.

This challenge has become increasingly complex because the Indonesian trucking industry continues to experience market structure distortions. Syafrianita et al. (2024) explained that the trucking market structure tends to be imbalanced due to the dominance of large companies, limited tariff transparency, and intense price competition. These conditions place pressure on small and medium-sized trucking companies by reducing operational margins and limiting their ability to invest in distribution technology. Purnomo and Syafrianita (2024) emphasized that high operational cost pressures can reduce supply chain efficiency and negatively affect logistics distribution performance.

Meanwhile, logistics digital transformation has developed through the implementation of Transportation Management Systems (TMS), GPS tracking, freight marketplaces, dashboard monitoring, and real-time distribution data integration. Purnomo et al. (2024) explained that logistics digitalization can improve distribution visibility, accelerate operational decision-making, and optimize fleet utilization. However, the effectiveness of logistics digitalization is highly dependent on coordination quality and supply chain integration among distribution actors. Purnomo (2009) explained that supply chain collaboration can improve information sharing, distribution synchronization, and logistics fleet management effectiveness.

The object of this research was PT Putera Sarana Usaha (PSU Expedisi), a transportation and goods distribution service company operating in the domestic trucking sector. The company continues to experience challenges related to high distribution costs, mismatches between Delivery Orders (DOs) and fleet availability, low vehicle utilization, and increasing empty fleet movements. These conditions indicate that truck transportation costs are influenced not only by operational factors but also by logistics digitalization, trucking market structure, and supply chain collaboration effectiveness. Therefore, this study analyzed the influence of load imbalance, market structure distortion, and logistics digitalization on truck transportation costs through supply chain collaboration as a mediating variable to develop a model for improving distribution efficiency in the Indonesian trucking industry.

The empirical phenomenon examined in this study was derived from the high cost of truck transportation in Indonesia, which remains a major contributor to national logistics costs. Purnomo (2022) explained that high national logistics costs reflect low distribution efficiency and insufficient supply chain integration compared with other ASEAN countries. Syafrianita et al. (2025) also emphasized that the effectiveness of logistics transportation systems significantly determines distribution continuity, supply stability, and national economic competitiveness. In operational practice, Purnomo et al. (2023) explained that many trucking

companies experience difficulties in obtaining return loads after delivery activities, causing vehicles to return without cargo or experience empty backhaul. Mustafia et al. (2023) emphasized that these conditions result in low fleet utilization, increased fuel consumption, inefficient operational time, and higher distribution costs per trip. Purnomo and Syafranita (2024) further explained that empty travel costs are ultimately transferred into shipping rates, increasing overall logistics service costs.

Load imbalance is also influenced by the uneven distribution of industrial centers across regions. Purnomo (2022) explained that industrial and logistics activities in Indonesia remain concentrated on Java Island, causing unbalanced freight flows and increasing the risk of load imbalance between regions. This condition reduces fleet utilization efficiency and increases the potential for empty vehicle movements. Syafranita et al. (2024) added that limited distribution coordination and insufficient logistics information integration further reduce the efficiency of national trucking transportation.

Another empirical phenomenon is related to the competitiveness of the trucking market structure, which remains imperfect. Syafranita et al. (2024) explained that the national trucking industry continues to experience market structure distortions due to the dominance of large companies in certain distribution channels, limited transportation tariff transparency, and intense price competition. These conditions create operational pressure for small and medium-sized trucking companies, limiting their ability to improve service quality and invest in distribution technology. Purnomo and Syafranita (2024) emphasized that market structure inequality influences distribution cost formation and reduces supply chain efficiency.

Furthermore, logistics digital transformation in Indonesia continues to face several limitations. Syafranita et al. (2024) explained that many small-scale trucking companies still rely on manual freight-search systems and lack real-time distribution data integration. Purnomo et al. (2024) emphasized that limited logistics digitalization contributes to slower distribution coordination, restricted fleet visibility, and less effective operational decision-making. In addition, Purnomo et al. (2024) explained that technology implementation without sufficient supply chain integration and information sharing among distribution actors limits the achievement of optimal operational efficiency.

Empirical conditions demonstrate that truck transportation costs in Indonesia remain influenced by various structural and operational challenges. The high occurrence of empty backhaul causes fleets to return without cargo, increasing transportation costs and reducing distribution efficiency. Furthermore, unequal freight flows between regions result in low fleet utilization because logistics activities remain concentrated in specific areas. These challenges are intensified by limited transportation tariff transparency and the dominance of large companies, which contribute to market structure distortions, unequal competitiveness, and unfair price competition within the national trucking industry.

In addition, the level of logistics digitalization among trucking companies remains relatively limited. Many processes related to freight matching, fleet management, and distribution coordination are still conducted manually, slowing the acquisition of return loads and reducing operational effectiveness. The utilization of technologies such as Transportation Management Systems (TMS), GPS tracking, fleet monitoring systems, and digital freight marketplaces remains suboptimal. Consequently, distribution visibility, real-time data

integration, and synchronization among supply chain actors remain limited, preventing the full realization of logistics efficiency improvements.

Previous studies have generally focused on individual operational aspects, such as route optimization, logistics costs, fleet utilization, and logistics digitalization. Research integrating load imbalance (empty backhaul), market structure distortion, logistics digitalization, supply chain collaboration, and truck transportation costs within a single research model remains limited, particularly in the context of the Indonesian trucking industry. Therefore, this study was developed to analyze the influence of load imbalance, market structure distortion, and logistics digitalization on truck transportation costs through supply chain collaboration as a mediating variable, thereby producing a more efficient, integrated, and sustainable distribution model.

METHOD

Types of Research

This study employed a quantitative approach with an explanatory research design to examine the causal relationships among load imbalance (empty backhaul), market structure distortion, logistics digitalization, supply chain collaboration, and truck transportation costs at PT Putera Sarana Usaha (PSU Expedisi). The research applied a cross-sectional approach, with data collected during a single observation period to represent the operational conditions of the trucking company. Based on a positivist paradigm, this study measured the research variables objectively using numerical data and statistical analysis to test the formulated hypotheses. Data analysis was conducted using Structural Equation Modeling–Partial Least Squares (SEM–PLS), as this method is appropriate for examining complex models involving direct relationships and mediation effects among latent constructs and can accommodate data that do not necessarily meet normality assumptions. Through this approach, the study aimed to develop an empirical model explaining the factors influencing truck transportation costs within the Indonesian trucking industry.

Population and Sample

The population in this study is all individuals who are directly involved in distribution and transportation operational activities at PT Putera Sarana Usaha (PSU Expedisi), such as operational managers, distribution supervisors, fleet dispatchers, logistics administration staff, drivers, and transportation partners who understand the process of fleet management, distribution, and digital logistics systems. The research sample was determined using purposive sampling techniques with the criteria that respondents have direct involvement in trucking operations, at least one year of work experience, understand fleet and distribution management, and have knowledge of digital logistics systems. Based on the SEM-PLS approach, the minimum sample number was calculated using the 10 times rule method and sample size recommendations for complex models, so that 155–170 respondents were determined to be able to produce stable, valid, and reliable parameter estimates. The research analysis unit is individuals involved in trucking distribution operational activities, so the data obtained is expected to be able to represent empirical conditions related to the influence of logistics digitalization, market structure distortions, load imbalances, and supply chain collaboration on truck transportation costs in Indonesia.

Data Collection

Data collection is an essential stage in quantitative research because the quality of the empirical data obtained will determine the validity of the construct, the reliability of the model, and the accuracy of the interpretation of the research results. In research based on Structural Equation Modeling–Partial Least Squares (SEM-PLS), the data collection process not only aims to obtain statistical information, but also builds empirical representations that are able to explain the relationships between latent variables in a systematic and measurable manner (Hair et al., 2020). Therefore, this study uses a comprehensive data collection approach through a combination of primary data and secondary data so that the research results have high academic strength and practical relevance.

Primary data was obtained directly from operational activities and respondents involved in the distribution process at PT Putera Sarana Usaha (PSU Expedisi), while secondary data was obtained through scientific journals, industry reports, company documents, government regulations, and national statistical publications. The use of these two types of data was carried out to increase the validity of the research through the data triangulation process so that the resulting interpretation is not only normative, but also reflects the empirical condition of the trucking industry in Indonesia (Creswell, 2018).

The data collection method in this study consisted of literature study, field observation, semi-structured interviews, and questionnaire distribution. The combination of methods was chosen because research on truck transportation costs is influenced by various multidimensional factors, ranging from fleet operational efficiency, load imbalances, trucking market structure, to the level of implementation of digital logistics and freight matching systems (Purnomo & Pratiwi, 2022).

Data Analysis Techniques

The data analysis stage starts from editing, coding, and input data into SmartPLS, then continues with the evaluation of the outer model and inner model. The inner model test includes the analysis of the determination coefficient (R^2), effect size (f^2), predictive relevance (Q^2), and goodness of fit model to assess the model's ability to explain the research phenomenon. Furthermore, hypothesis testing is carried out using the bootstrapping technique to obtain the path coefficient (β), t-statistic, and p-value values. The relationship between variables is stated to be significant if it has a t-statistical value of ≥ 1.96 and a p-value of < 0.05 . Through this stage, the research can comprehensively evaluate the direction, strength, and significance of the influence between variables in explaining the factors that affect the cost of truck transportation in Indonesia.

RESULTS AND DISCUSSION

Description of Research Data

This study uses the Structural Equation Modeling–Partial Least Squares (SEM-PLS) approach to analyze the relationship between Logistics Digitalization (X3), Market Structure Distortion (X2), Load Imbalance (X1), Supply Chain Collaboration (Z), and Truck Transportation Costs (Y). Data were obtained from 203 respondents from trucking and logistics industry players in Indonesia. All data were declared worthy of analysis because no missing value or data processing errors were found. The following Figure 4.5 shows the SEM-PLS Research Model.

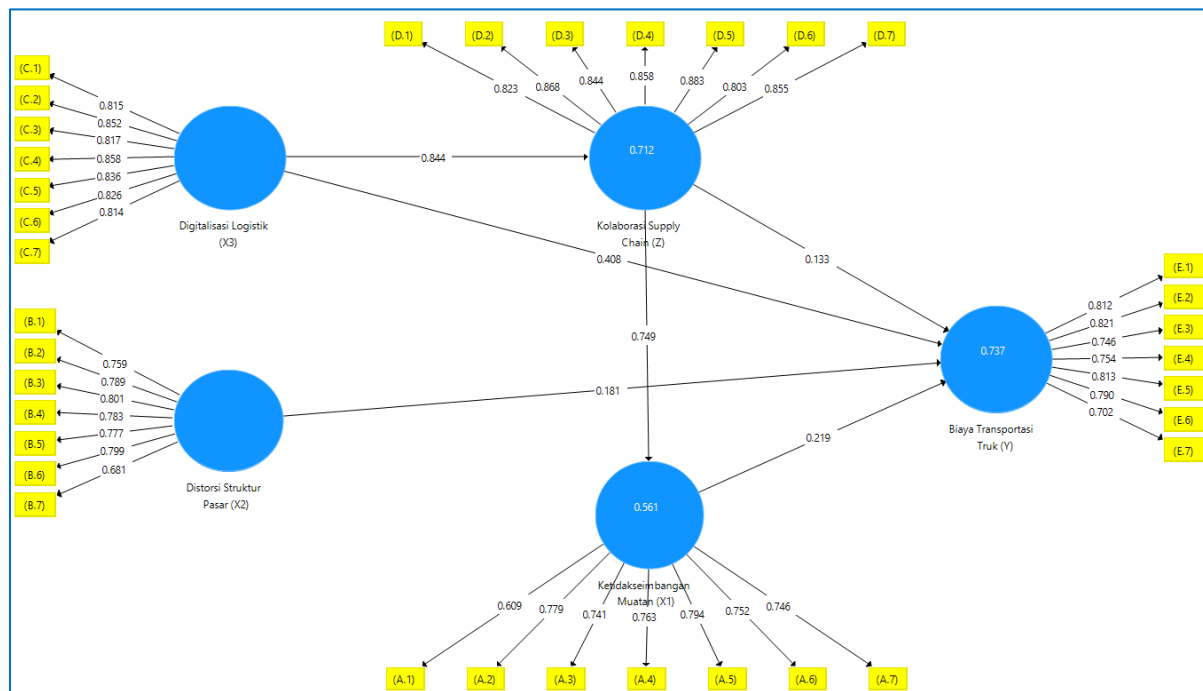


Figure 1. SEM-PLS Research Model and Outer Loading Value

Source: Arumdita Dian K., 2026

Evaluation of Measurement Models (Outer Model)

The evaluation of the outer model is carried out to ensure that all indicators are able to measure latent constructs validly and reliably through convergent validity, discriminant validity, and construct reliability tests according to the analysis stages in Chapter III.

a. Convergent Validity

Based on the results of outer loading seen in Figure 4.5, all indicators have values above the minimum limit of 0.60 so that they meet the criteria for convergent validity. In addition, the Average Variance Extracted (AVE) value of all constructs as seen in Table 4.1 is above 0.50 which shows that each construct is able to explain more than 50% of the variance of the indicator.

Table 1 Convergent Validity and AVE

	Average Variance Extracted (AVE)
Truck Transportation Cost (Y)	0.605
Logistics Digitalization (X3)	0.691
Market Structure Distortion (X2)	0.594
Load Imbalance (X1)	0.552
Supply Chain Collaboration (Z)	0.719

Source : Arumdita Dian K., 2026

b. Discriminant Validity

The discriminant validity test aims to ensure that each latent construct in the research model has different characteristics and is able to measure the specific concept without overlapping with other constructs. In this study, discriminant validity was evaluated using two approaches, namely the Fornell-Larcker Criterion and the Heterotrait-Monotrait Ratio (HTMT). The results of the test are presented in Table 4.3 and Table 4.4

Table 2 Fornell-Larcker Criterion

	Truck Transportation Cost (Y)	Logistics Digitalization (X3)	Market Structure Distortion (X2)	Load Imbalance (X1)	Supply Chain Collaboration (Z)
Truck Transportation Cost (Y)	0.778				
Logistics Digitalization (X3)	0.810	0.831			
Market Structure Distortion (X2)	0.748	0.712	0.771		
Load Imbalance (X1)	0.768	0.734	0.827	0.743	
Supply Chain Collaboration (Z)	0.771	0.844	0.714	0.749	0.848

Source: Arumdita Dian K., 2026

Table 3 HTMT

	Truck Transportatio n Cost (Y)	Logistics Digitalizatio n (X3)	Market Structure Distortio n (X2)	Load Imbalanc e (X1)	Supply Chain Collaboratio n (Z)
Logistics Digitalization (X3)	0.891				
Market Structure Distortion (X2)	0.838	0.786			
Load Imbalance (X1)	0.872	0.816	0.948		
Supply Chain Collaboration (Z)	0.842	0.905	0.783	0.829	V

Source : Arumdita Dian K., 2026

Based on Table 4.3, the test results using the Fornell-Larcker Criterion show that the square root value of Average Variance Extracted (AVE) in each construct is on the main diagonal of the matrix, which is 0.778 for Truck Transportation Cost (Y), 0.831 for Logistics Digitalization (X3), 0.771 for Market Structure Distortion (X2), 0.743 for Load Imbalance (X1), and 0.848 for Supply Chain Collaboration (Z). In general, this value is higher than most correlations between constructs, indicating that each variable has a good ability to explain its own indicators compared to other constructs.

However, there are some relatively high correlation values, such as the relationship between Logistics Digitalization (X3) and Supply Chain Collaboration (Z) of 0.844, and the relationship between Market Structure Distortion (X2) and Load Imbalance (X1) of 0.827. The high correlation indicates a strong conceptual relationship between variables in the context of a logistics system, but it is still acceptable because each construct is still built based on different indicators and has a different theoretical basis.

Furthermore, the test results using HTMT (Heterotrait-Monotrait Ratio) in Table 4.4 show that most HTMT values are below the tolerance limit of 0.90, such as the relationship between Truck Transportation Costs and Market Structure Distortions (0.838), Truck Transportation Costs with Load Imbalances (0.872), and Supply Chain Collaboration with Load Imbalances (0.829). These values show that the validity of the discriminator has been well met.

However, there are two construct pairs that have an HTMT value slightly above the conservative limit of 0.90, namely the relationship between Logistics Digitalization (X3) and Supply Chain Collaboration (Z) of 0.905 and the relationship between Market Structure Distortion (X2) and Load Imbalance (X1) of 0.948. This condition indicates a high conceptual proximity between the two variable pairs. In the context of this study, this phenomenon can

still be understood theoretically because the implementation of logistics digitalization in companies is very closely related to increasing collaboration between supply chain players, while market structure distortion directly affects the emergence of load imbalances in the truck transportation industry.

Substantively, the strong relationship between the constructs actually supports the conceptual framework of the research that places these variables in a single logistics system that affects each other. In addition, the results of previous external loading, AVE, and composite reliability tests have shown that each construct has excellent convergent validity and reliability, so that the potential for overlap between constructs does not reduce the overall quality of the measurement model.

Based on the results of the evaluation using the Fornell-Larcker Criterion and HTMT, it can be concluded that the measurement model in this study has adequate discriminant validity. Each construct is able to represent variables that are measured independently and can be distinguished from other constructs, so that all latent variables are suitable for further analysis at the stage of structural model evaluation (inner model) and testing of research hypotheses.

Reliability Test

Construct reliability testing is carried out to ensure that each latent construct in the study has a good level of internal consistency in measuring the concept being studied. High reliability indicates that the constituent indicators of a construct are able to provide stable and consistent measurement results. In this study, reliability was evaluated using three main parameters, namely Cronbach's Alpha, rho_A, and Composite Reliability (CR). The test results are presented in Table 4.

Table 4 Construct Reliability and Validity

	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
Truck Transportation Cost (Y)	0.891	0.893	0.914	0.605
Logistics Digitalization (X3)	0.925	0.925	0.940	0.691
Market Structure Distortion (X2)	0.886	0.888	0.911	0.594
Load Imbalance (X1)	0.863	0.868	0.895	0.552
Supply Chain Collaboration (Z)	0.935	0.936	0.947	0.719

Source : Arumdita Dian K., 2026

Based on the test results in Table 4.5, the entire construct has a Cronbach's Alpha value above the minimum limit of 0.70, which indicates that each variable has an excellent level of internal consistency. The highest Cronbach's Alpha value was found in the Supply Chain Collaboration variable (Z) of 0.935, followed by Logistics Digitalization (X3) of 0.925, Truck Transportation Cost (Y) of 0.891, Market Structure Distortion (X2) of 0.886, and Load Imbalance (X1) of 0.863. All of these values indicate that the indicators in each construct are able to measure the same variables consistently.

In addition to Cronbach's Alpha, reliability evaluations were also conducted using rho_A, which is considered more accurate in the Partial Least Squares Structural Equation Modeling (PLS-SEM) approach because it takes into account the actual contribution of each indicator to latent constructs. The test results showed that all rho_A values were in the range of 0.868 to 0.936, or well above the threshold value of 0.70. These findings reinforce that each construct has high internal reliability and is capable of producing consistent measurements.

Furthermore, the test using Composite Reliability (CR) showed excellent results, with the overall value being above 0.90, which is 0.914 for Truck Transportation Cost (Y), 0.940 for Logistics Digitalization (X3), 0.911 for Market Structure Distortion (X2), 0.895 for Load Imbalance (X1), and 0.947 for Supply Chain Collaboration (Z). These values exceed the minimum limit of 0.70, thus indicating that the combination of indicators in each construct has a very strong level of reliability in explaining the latent variables they represent.

In addition to confirming the reliability of the construct, the Average Variance Extracted (AVE) on all variables also shows values above 0.50, which ranges from 0.552 to 0.719. This indicates that more than 50% of the variation of the indicator can be explained by the latent construct in question, thus reinforcing the fulfillment of the validity of the convergence. The Supply Chain Collaboration variable (Z) had the highest AVE value of 0.719, indicating an excellent ability to explain the variance of its indicators, while the Load Imbalance variable (X1) had the lowest AVE value of 0.552, but it was still above the required minimum limit so that it still met the eligibility criteria.

Overall, the results of Cronbach's Alpha, rho_A, Composite Reliability, and Average Variance Extracted (AVE) tests show that all constructs in the research model have an excellent level of reliability and convergent validity. Thus, each latent variable is declared to be able to measure the concepts being studied consistently and accurately, so that the measurement model meets the requirements to continue at the stage of structural model evaluation (inner model) and research hypothesis testing.

Evaluation of Structural Models (Inner Model)

Internal model evaluation or structural model is carried out to assess the ability of the research model to explain the causal relationship between latent constructs that have been built. In the Partial Least Squares Structural Equation Modeling (PLS-SEM) approach, one of the main indicators used to evaluate structural models is the determination coefficient (R^2). The R^2 value indicates the proportion of variations in endogenous variables that can be explained by exogenous variables in the research model. The higher the R^2 value, the greater the model's ability to explain the phenomenon being studied.

According to the criteria presented by Hair et al., the R^2 value of 0.75 is categorized as strong (substantial), 0.50 is categorized as moderate, and 0.25 is categorized as weak (weak). Therefore, the evaluation of the R^2 value is the basis for assessing the level of predictive ability of the structural model.

Table 5 Value of Determination Coefficient (R^2)

Variable	R^2	Categories
Truck Transportation Costs	0,737	Strong
Supply Chain Collaboration	0,712	Strong
Load Imbalance	0,561	Moderate

Source : Arumdita Dian K., 2026

Based on Table 5, Truck Transportation Cost (Y) has an R^2 value of 0.737, which means that 73.7% of the variation in truck transportation costs can be explained by variables in the model, while the remaining 26.3% is influenced by other factors outside the study. This value shows that the model has strong explanatory capabilities. The Supply Chain Collaboration

variable (Z) obtained an R^2 value of 0.712, which indicates that 71.2% of the variation can be explained by exogenous variables in the model, while 28.8% are influenced by other factors outside the model, so it belongs to the strong category.

Meanwhile, the Load Imbalance (X1) has an R^2 value of 0.561, which means that 56.1% of the variation can be explained by variables in the model, while 43.9% is influenced by other factors, so it belongs to the moderate category.

Overall, the test results showed that the research model had good predictive capabilities, with two endogenous variables in the strong category and one variable in the moderate category, so the model was suitable for hypothesis testing at a later stage.

Effect Size (f^2)

Effect size testing was carried out to determine the amount of contribution of each independent variable to the dependent variable. Interpretation was carried out based on the criteria of Hair et al., namely 0.02 (small), 0.15 (medium), and 0.35 (large). The test results showed that each construct had a different level of contribution in explaining changes in truck transportation costs.

Table 6 f Square

	Truck Transportation Cost (Y)	Logistics Digitalization (X3)	Market Structure Distortion (X2)	Load Imbalance (X1)	Supply Chain Collaboration (Z)
Truck Transportation Cost (Y)					
Logistics	0.164				2.472
Digitalization (X3)					
Market Structure Distortion (X2)	0.036				
Load Imbalance (X1)	0.047				
Supply Chain Collaboration (Z)	0.017			1.279	

Source : Arumdita Dian K., 2026

Based on Table 6, Logistics Digitalization (X3) has a moderate influence on Truck Transportation Costs (Y) with a value of f^2 of 0.164, and has a very large influence on Supply Chain Collaboration (Z) with a value of 2.472. These findings show that logistics digitalization is a major factor in increasing collaboration between supply chain actors.

Furthermore, Market Structure Distortion (X2) has an f^2 value of 0.036 to Truck Transportation Costs (Y), while Load Imbalance (X1) has a value of 0.047. Both values fall into the category of minor influences, but still contribute to changes in truck transportation costs.

Meanwhile, Supply Chain Collaboration (Z) has an f^2 value of 0.017 to Truck Transportation Cost (Y) which shows a very small influence, but has a very large influence on Load Imbalance (X1) with a value of 1.279. This indicates that the increase in supply chain collaboration plays a significant role in reducing load imbalance.

Overall, the results of the effect size (f^2) test showed that Logistics Digitalization was the variable with the most dominant contribution in the model, mainly through the improvement of Supply Chain Collaboration, while other variables made a small to moderate contribution to changes in Truck Transportation Costs. These findings show that the

effectiveness of digitalization and supply chain collaboration is an important factor in improving the efficiency of logistics systems and reducing truck transportation costs.

Path Coefficient

The path coefficient is used to show the direction and magnitude of the influence between variables in the structural model. The greater the value of the coefficient, the stronger the influence of the independent variable on the dependent variable. The estimation results show that all relationships between variables have a positive direction, so that an increase in exogenous variables will be followed by an increase in the endogenous variables they affect.

Based on Table 5 and Figure 6, the greatest influence is shown by Logistics Digitalization on Supply Chain Collaboration ($\beta = 0.844$), which indicates that increasing digitalization is able to significantly encourage collaboration between supply chain actors. Furthermore, Supply Chain Collaboration has a positive effect on Load Imbalance ($\beta = 0.749$), showing that changes in the level of collaboration are closely related to changes in load balance conditions.

Table 7 Path Coefficient

Relationships	Coefficient (β)
Logistics Digitalization (X3) $\rightarrow$ Truck Transportation Costs (Y)	0,408
Market Structure Distortion (X2) $\rightarrow$ Truck Transportation Cost (Y)	0,181
Load Imbalance (X1) $\rightarrow$ Truck Transportation Cost (Y)	0,219
Supply Chain Collaboration (Z) $\rightarrow$ Truck Transportation Costs (Y)	0,133
Logistics Digitalization (X3) $\rightarrow$ Supply Chain Collaboration (Z)	0,844
Supply Chain Collaboration (Z) $\rightarrow$ Load Imbalance (X1)	0,749

Source: Arumdita Dian Kusumawati, 2026

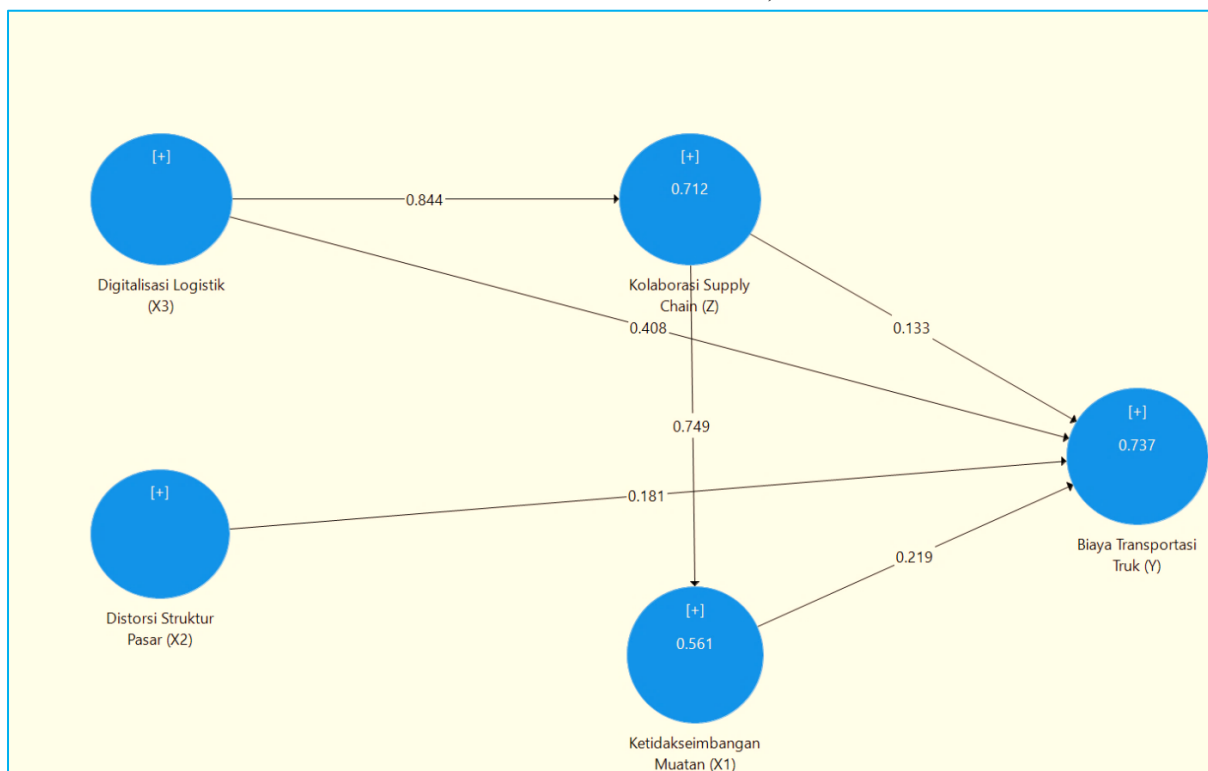


Figure 2. Path Coefficient Chart

Source : Arumdita Dian K., 2026

Indirect Effect

Indirect effect analysis was carried out to identify the influence of an exogenous variable on endogenous variables through mediation variables in a structural model. This test aims to find out whether the relationship between variables occurs directly or through the mediation mechanism that has been designed in the research model.

The results of the analysis show that Logistics Digitalization (X3) affects Truck Transportation Costs (Y) through Supply Chain Collaboration (Z) and Load Imbalance (X1). These findings indicate that the implementation of logistics digitalization not only affects transportation costs directly, but also through increased collaboration between supply chain actors which further impacts changes in the level of load imbalance.

Table 8 Specific Indirect Effects

Supply Chain Collaboration (Z) -> Load Imbalance (X1) -> Truck Transportation Cost (Y)	0.164
Logistics Digitalization (X3) -> Supply Chain Collaboration (Z) -> Load Imbalance (X1) -> Truck Transportation Costs (Y)	0.138
Logistics Digitalization (X3) -> Supply Chain Collaboration (Z) -> Truck Transportation Costs (Y)	0.113
Logistics Digitalization (X3) -> Supply Chain Collaboration (Z) -> Load Imbalance (X1)	0.632

Source : Arumdita Dian K., 2026

Based on Table 8, the Logistics Digitalization → Supply Chain Collaboration → Load Imbalance pathway resulted in an indirect coefficient value of 0.632, which shows that logistics digitalization has a strong influence in increasing supply chain collaboration so that it has an impact on changing load imbalance conditions.

In addition, the total indirect influence of Logistics Digitalization on Truck Transportation Costs of 0.251 shows that the existence of mediation variables makes a significant contribution in explaining the relationship between variables. Thus, Supply Chain Collaboration and Load Imbalance plays a role as a mediation mechanism that strengthens the influence of logistics digitalization on changes in truck transportation costs.

Summary of Research Results

The results of the outer model evaluation showed that all constructs had met the criteria of validity and reliability, so that all indicators were declared feasible to measure the research variables. Meanwhile, the evaluation of the inner model showed good explanatory ability with a value of R^2 Truck Transportation Cost of 0.737, Supply Chain Collaboration of 0.712, and Load Imbalance of 0.561.

The line coefficient analysis showed that Logistics Digitalization had the most dominant influence on Supply Chain Collaboration ($\beta = 0.844$), which further affected Load Imbalance ($\beta = 0.749$) and had implications for Truck Transportation Costs. The results of effect size and indirect effect also support the importance of the role of digitalization in improving the efficiency of the logistics system.

Overall, the research model has met all PLS-SEM statistical criteria, so it is declared valid, reliable, and suitable for hypothesis testing.

The discussion of the research results aims to interpret the empirical findings obtained through the SEM-PLS analysis by relating them to the underlying theory of research and the

results of previous research. The discussion was conducted to explain how logistics digitalization, market structure distortions, load imbalances, and supply chain collaboration contribute to the formation of truck transportation costs in Indonesia.

The Effect of Logistics Digitalization on Truck Transportation Costs

The results of the hypothesis test show that logistics digitalization has an influence on the cost of truck transportation. These findings show that the use of digital technology is an important factor in improving the efficiency of distribution and fleet management.

Logistics digitalization allows companies to obtain information about delivery requests, fleet locations, traffic conditions, and load availability in real time. This information accelerates the operational decision-making process so that vehicle waiting time can be reduced and fleet utilization increased.

Based on the Resource-Based View (RBV) perspective, a company's ability to manage digital technology is a strategic resource that is able to create a competitive advantage. An integrated digital system results in better operational coordination, improves the accuracy of distribution planning, and reduces transaction costs due to information delays.

The findings of this study also support the concept of Digital Supply Chain Management, which explains that the integration of information technology is able to increase supply chain transparency and optimize the utilization of logistics resources. The higher the level of digitalization, the greater the opportunity for companies to reduce activities that do not provide added value, including vehicle waiting times and unloaded trips.

In the context of the Indonesian trucking industry, digital transformation is still taking place gradually. Large companies have generally used digital systems to manage fleets and distribution, while most small companies still use conventional methods. The difference in the level of technology adoption causes operational efficiency between companies to be uneven and affects high transportation costs.

The results of this study show that investment in digital technology needs to be seen as a long-term strategic investment that is able to increase fleet productivity while strengthening the company's competitiveness in the midst of increasingly dynamic competition in the logistics industry.

The Effect of Market Structure Distortion on Truck Transportation Costs

This study shows that market structure distortions affect truck transportation costs. The findings indicate that market characteristics are one of the factors that determine the efficiency of distribution costs.

According to the Structure-Conduct-Performance (SCP) theory, the market structure influences the behavior of business actors which ultimately determines the performance of the industry. If the market is characterized by information asymmetry, the dominance of certain actors, or an unbalanced level of competition, then the tariff formation mechanism does not run efficiently.

This condition is still seen in the Indonesian trucking industry, which has a high level of fragmentation. Many companies operate independently with limited access to information, making the process of finding cargo and negotiating tariffs less than optimal. This situation increases transaction costs and causes some fleets to operate below ideal capacity.

The results of the study show that the establishment of a more transparent market through the use of digital platforms and more open information exchange can improve distribution efficiency and improve the mechanism of determining transportation rates.

The Effect of Load Imbalance on Truck Transportation Costs

Load imbalance is one of the main factors that cause high truck transportation costs. The results show that the higher the empty backhaul rate, the greater the operational costs that the company must bear.

This phenomenon occurs because vehicles that return without carrying a load still require fuel costs, driver wages, vehicle maintenance, and asset depreciation. All of these costs do not generate revenue, so they are charged on loaded trips and increase transportation rates.

From the perspective of Transportation Cost Theory, transportation efficiency is greatly influenced by the level of fleet utilization. The higher the rate of vehicle capacity utilization, the lower the average cost of distribution. Conversely, low fleet utilization causes an increase in costs per unit of goods transported.

In the context of Indonesia, the imbalance in distribution flows between regions causes the opportunity to obtain return loads is still low, especially on routes with unbalanced trade volumes. Therefore, the development of freight matching systems, cargo consolidation, and integration of logistics information is a strategic step to reduce empty trips.

These findings confirm that increasing fleet utilization is one of the most effective strategies in reducing national logistics costs without having to increase the number of vehicles.

The Effect of Supply Chain Collaboration on Truck Transportation Costs

Supply chain collaboration plays a role in improving distribution efficiency through better coordination between supply chain players. The integration of information regarding demand, delivery schedules, and fleet capacity allows companies to plan distribution more effectively.

Based on Supply Chain Integration Theory, collaboration improves the synchronization of logistics activities so that it can reduce waste and increase productivity. In the trucking industry, collaboration can be realized through sharing load information, joint fleet utilization, and shipping consolidation.

The results of the study show that increased collaboration encourages more optimal utilization of vehicle capacity so that distribution costs can be reduced. Thus, collaboration not only improves service quality, but also results in economic efficiency for all supply chain actors.

The Role of Supply Chain Collaboration Mediation and Load Imbalance

The main contribution of this research lies in proving that the relationship between logistics digitalization and transportation costs does not only occur directly, but also through supply chain collaboration mechanisms and load imbalances.

Digitalization improves the quality of information and connectivity between organizations, resulting in better distribution coordination. Increased collaboration allows cargo matching with fleets to be done more quickly so that the frequency of empty trips can be reduced.

The decrease in empty trips increases fleet utilization and ultimately lowers transportation costs. These findings show that the benefits of digitalization will be more optimal if supported by strong collaboration between supply chain actors.

The relationship model shows that logistics efficiency is the result of an interaction between technology, organizational coordination, and operational optimization. This approach provides a more comprehensive perspective than previous studies that generally only test the direct relationship between variables.

Research Implications

Theoretically, this study enriches the study of logistics management by integrating Digital Logistics Theory, Supply Chain Integration Theory, Transportation Cost Theory, and Structure-Conduct-Performance Theory in one conceptual model to explain the determinants of truck transportation costs.

In practical terms, the results show that trucking companies need to accelerate digital transformation, increase collaboration with supply chain partners, and optimize fleet utilization through freight matching systems. On the other hand, the government can encourage the development of a national logistics digital ecosystem, strengthen the interoperability of logistics platforms, and create a more transparent and competitive market structure.

Overall, this study shows that reducing truck transportation costs requires an integrated approach through strengthening digital technology, increasing supply chain collaboration, reducing load imbalances, and improving market structures. The synergy of these four aspects is expected to increase national logistics efficiency and strengthen the competitiveness of the freight transportation sector in Indonesia.

CONCLUSION

This study aimed to analyze the influence of logistics digitalization, market structure distortion, load imbalance, and supply chain collaboration on truck transportation costs in Indonesia using the SEM–PLS approach. The results showed that logistics digitalization, market structure distortion, load imbalance, and supply chain collaboration significantly influenced truck transportation costs. Logistics digitalization improved distribution efficiency through enhanced fleet utilization, information integration, and accelerated operational processes, while market structure distortion and load imbalance increased transportation costs due to reduced distribution efficiency and suboptimal fleet utilization. Supply chain collaboration played an important role in improving coordination, synchronizing distribution activities, and reducing empty backhaul movements, thereby contributing to lower transportation costs. The findings also demonstrated that logistics digitalization strengthened supply chain collaboration, which subsequently contributed to reducing load imbalance.

Therefore, improving truck transportation efficiency requires an integrated approach involving digital transformation, stronger collaboration among supply chain actors, reduction of empty backhaul movements, and the development of a more transparent and competitive market structure. Based on these findings, trucking companies are encouraged to accelerate the adoption of digital technologies and strengthen distribution collaboration, while governments and regulators should support the development of digital logistics ecosystems, improve market transparency, and optimize national freight-matching systems. Future research is recommended to incorporate additional variables, such as infrastructure quality, fuel prices, government regulations, and operational costs, while expanding the research scope through broader samples and longitudinal or mixed-method approaches to obtain a more comprehensive understanding of the factors influencing truck transportation costs in Indonesia.

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