İSTANBUL UNIVERSITY PRESS

Acta Infologica

Acta Infologica,
ACIN 2025, 9 (2): 641–663

https://doi.org/10.26650/acin.1785557
Submitted: 16.09.2025
Revision Requested: 18.11.2025
Last Revision Received: 04.12.2025
Accepted: 04.12.2024

Research Article

Open Access

A Simulation Model Based on System Dynamics for Factors Affecting Logistics Development and Planning

Özlem Karadağ Albayrak [1]

[1] Kafkas University, Faculty of Economics and Administrative Sciences,Department of International Trade and Logistics Department, Kars, Türkiye

Abstract

This article focuses on the need to understand the dynamic nature of the logistics system despite the difficulty of predicting its development. Logistics systems develop as complex structures with linear and nonlinear loops and are, affected by social, economic, and environmental factors. The development of countries' logistics capacities and logistics performance in the international arena mutually affect each other. The development of logistics performance increases demand for the logistics sector. Therefore, this demand increase in the logistics sector or the development of the sectoral capacity affects the basic economic indicators. The interaction between the effective factors in logistics development is important for industry decision-makers, policy-making, and future planning, and traditional logistics modeling is insufficient to model this complex structure. This study uses a system dynamics simulation to investigate the effect of changes in different dynamics on Turkiye's logistics capacity development. For this purpose, we used a system dynamics approach methodology based on the modeling of complex systems with cause-effect analysis and feedback loop structures. With this method, Turkiye's logistics capacity development is monitored under different scenarios. This study demonstrates how system dynamics can improve the knowledge of complex logistics behavior. The comparison results of different scenarios indicate that the development of foreign trade activities has been the most important development factor in Turkiye's logistics capacity performance. Development in investment decisions is another important factor. These effects cause different levels of change in the capacity utilization of different modes.

Keywords System Dynamics Analysis · Simulation · Logistics

Citation: Karadağ Albayrak, Ö. (2025). A Simulation Model Based on System Dynamics for Factors Affecting Logistics Development and Planning. Acta Infologica, Advance Online Publication.. *Acta Infologica*, *9*(2), 641-663. https://doi.org/10.26650/acin.1785557

Corresponding author: Özlem Karadağ Albayrak ozlemkaradagalbayrak@gmail.com

Introduction

The most important factors for understanding nations' economic growth and development levels are the country's economic indicators (Sezer and Abasiz, 2017). Logistics has become a key driver of economic growth, especially in the context of globalization, and it indirectly strengthens sectoral competitiveness. In addition to the role of modern logistics in economic development, regional logistics is also effective in the development of various industries, such as regional trade, tourism, and finance (Bi et al., 2020). Therefore, there is an increasing need to reevaluate logistics in detail to support economic growth and enhance competitiveness (Bugarčić et al., 2023).

Logistics encompasses a wide range of activities, from transport, storage, and consolidation to the handling of products. Logistics refers to the movement of products along the supply chain from the source of raw materials to the final destination (McKinnon, 2012). Logistics is a complex process influenced by individuals, physical resources, policy frameworks, infrastructure, and the interactions among them. Like other complex social systems, modeling logistics processes involves challenges in identifying causal parameters and defining an appropriate system structure. Therefore, a complex logistics system should be evaluated and modeled using a systems approach. The drivers of logistics capacity and performance should be evaluated from multiple dimensions. Keeping the models relatively simple allows for more effective communication and stakeholder collaboration (Wiman et al., 2022).

The analysis of complex systems in nondeterministic and dynamic environments is discussed using simulation techniques (Castaneda et al., 2022). The system dynamics (SD) approach was applied among the simulation methods in this study. SD was developed by Forrester (1958-1961-1969) from MIT in the 1950s and is a suitable tool for strategic research on policy, analysis, and decision-making. SD is particularly effective because it captures nonlinear interactions and feedback mechanisms (Sterman, 2014). SD incorporates feedback loops, variables, and equations to demonstrate the functional relationships among the system components (Sterman, 2001). A feedback loop is a closed chain of causes and effects (Jifeng et al., 2018). Dynamic modeling begins by identifying the causal relationships among the system elements (Radzicki and Sterman, 1994).

The Republic of Turkiye is an important transit point for logistics flows from China to Europe due to its geographical location. To leverage this potential, Türkiye has launched major initiatives such as the Marmaray project and the Baku–Tbilisi–Kars railroad line. Table 1 summarizes Turkiye's development in the logistics sector in the last five years.

Table 1.

Turkiye's 5-year logistics sector development

Logistic indicators	2019	2023	Increase/Decrease
Number of employees in transportation and storage	933136	1727148	85.09%
Number of transportation and storage enterprises	430627	564967	31.20%
Transport services (% of commercial service exports)	33.013	36.91	11.79%
Transport services (percentage of commercial service imports)	34.57	38.49	1.33%
Freight transport amount on railway (tonne (thousand))	33536	32408	-3.36%
Total freight by airway (tonne)	4090168	4447865	8.75%
Total amount of cargo handled in ports (ton)	484168412	521079804	7.62%

Logistic indicators	2019	2023	Increase/Decrease
Tonne-km on road	339601	380178	11.95%
LPI	3.15*	3.4	7.93%
LSCI (maximum value in 2004 = 100)	57.67	62.88	9.03%
Gross domestic product (GDP) at current prices by type of economic activity at the A21 level value, share, and percentage change at current prices: transport and storage ((Thousand TRY)	145476482	937529907	544.45%
Gross domestic product at current prices by type of economic activity at the A21 level value, share, and percentage change at current prices: transport and storage (Share (%))	3,.4*	3.5	2.94%

*The 2018 score is presented because it was not published in 2019.

Almost all factors in the model, from road freight transport to GDP, have shown an upward trend when monitoring logistics development in Turkiye. These increases indicate the growing importance of the country's logistics sector. Recognizing the growing role of logistics, Türkiye established clear transport and logistics objectives in the 12th Development Plan (PRT, 2024). These objectives include improving intermodal transport, creating a safe, accessible, integrated, environmentally friendly, and cost-effective transport structure, and developing infrastructure that supports competitive production and exports to enhance Türkiye's position as a regional logistics hub. In addition, Türkiye launched the 2053 Transport and Logistics Master Plan, which sets the sector's long-term strategic targets.

• Increased number of logistics centers from 13 to 26

• Ranking among the top 10 countries in the Logistics Performance Index (LPI) ranking

• Expanding and improving the developed and extended

• Transforming Türkiye into a central corridor logistics base,

• Increased the number of logistics centers operating under international business standards

• Supporting Digital Transformation

• Customs control processes will be accelerated, and their efficiency will be increased.

Logistics is a key component of international trade. Türkiye's 2023 foreign trade statistics by transportation mode (Table 2) demonstrate that all logistics sub-elements are increasing in scale, reflecting the sector's continuous growth within the international trade framework.

Table 2.

Turkiye's foreign trade according to transportation mods ($) (TB, 2025)

Mods	Export (USD)	Export Share (%)	İmport(USD	Import share (%)
Highway ($)	83235	32.50%	66942	18.50%
Seaway ($)	143358	56.00%	195172	53.90%
Railway ($)	1960	0.70%	1996	0.50%
Airwayway ($)	25511	9.90%	53840	14.80%
Others ($)	1710	0.90%	43821	12.30%
Total	255774		361771	

It is vital for decision-makers that the level of logistics development, which is an important factor in international trade, is comparable. In this comparison, two current indicators are evaluated. The first is the LPI. This index is the most important determinant used for ranking logistics performance among countries and has been published by the World Bank since 2007. The logistics scores of countries are obtained by experts scoring the country on a scale of (1-5) according to six factors and determining the net score. These six basic evaluation factors can be explained as follows

- *Infrastructure:* It generally covers the costs of infrastructure construction and maintenance.
- *Quality of Logistics Performance*: It covers the adequacy and quality of logistics services, transport, and customs brokerage (La and Song, 2019).
- *International shipment:* It measures how simple it is to plan a shipment at reasonable costs (Ulker et al., 2024).
- *Timeliness*: It refers to the right time from the seven logistics lines.
- *Tracking and Tracing:*This component includes any connection in the supply chain for products, so traceability is the result of industry activity as a whole (Ulker et al., 2024).
- *Customs:* It covers the efficiency of customs and border management operations (La and Song, 2019).

Secondly, Liner Shipping Connectivity Index (LSCI) published by United Nations Conference on Trade and Development (UNCTAD) is another comparative indicator. This index aims to measure linear shipping connectivity to capture the level of integration in the existing linear shipping network. The country score in the index is obtained according to the following six indicators (Mohamad et al., 2015).

- *Scheduled ship calls*
- *Deployed capacity,*
- *The number of shipping companies and liner services,*
- *Average vessel size (%)*
- *Directly connected ports*

Directly connected ports, as captured by the LPI and LSCI indices, are more significant sources of trade and trade cost variation than geographical distance (Fugazza and Hoffmann, 2017). These indicators essentially present the outcomes of the current situation; however, they do not predict the consequences of different policies or investment decisions. To realize Turkiye's goal of becoming a logistics hub, and particularly to improve its international ranking, all relevant factors must be evaluated. The logistics performance and future planning of a country depend on many elements beyond these two indices. These elements are indirectly reflected in their sub-parameters. For instance, economic development is expected to drive infrastructure and capacity improvements.

This study focuses on Turkiye and proposes a logistics model. All factors directly and indirectly influencing the logistics sector have been modeled to capture their mutual interactions, and a simulation infrastructure has been established. These factors span a broad spectrum, ranging from indicators of economic development to measures of international trade, from the LPI to other global evaluation scales. The relationships among factors were identified and modeled using econometric methods. Various datasets and relevant resources were used for this study. Subsequently, the direct and indirect relationships between the factors were structured in a form suitable for simulation using a system dynamics approach. In this way, the complex structure of components and subcomponents was modeled from a system dynamics perspective, providing an effective means of analyzing complex systems.

Our research questions are as follows:

1. To examine how models developed under uncertainty regarding causal parameters and system structure can support decision-making by policymakers.
2. To analyze how logistics system interventions and planning adjustments affect efficiency, underlying assumptions, and outputs.
3. Derive efficiency rankings based on the outcomes of these scenario changes.

This article first reviews the literature on the selection of factors affecting Turkiye's logistics capacity development (Section 2). Section 3 then outlines the process of building the SD model. Subsequently, Section 4 presents the logistics system dynamics model for Turkiye and analyzes the system outputs for different scenarios. Finally, Section 5 highlights the main conclusions and addresses the research questions.

Literature review and conceptual framework

Evaluated logistics activities

Logistics activities are generally evaluated independently within the scope of transport and storage activities. The general definition of logistics refers to the processes and movement of transporting, planning, and storing products in domestic and foreign markets from the moment they are produced to meet consumers' needs to the consumption stage (Turna, 2024). Logistics is an important measure of trade flows in the global supply chain (Song and Lee, 2022). Logistics has quite comprehensive and different aspects. Logistics and its performance, which also have a significant effect on the productivity of countries (Saparovna Mukhtarova et al., 2018), are characterized by different levels of uncertainty due to the difficulties encountered in real life (Castaneda et al., 2022).

The terms logistics performance evaluation (Irfani, 2019) and supply chain performance evaluation (Campuzano et al., 2010, Liu, 2023) are encountered in the literature. The differences between these two terms have not been extensively discussed. However, the Council of Supply Chain Management Professionals (CSCMP, 2025) considers the supply chain concept to be more inclusive. In this study, both expressions are accepted as logistics performance evaluations.

The LPI is the most widely used metric in the literature. Numerous studies have discussed the weighting and interpretation of LPI indicators, arguing that sub-indicators should be evaluated with different levels of importance through more quantitative approaches rather than expert-based assessments (Kale and Tilki, 2024, Gürler et al., 2024, Stevic et al., 2024, Arman and Organ, 2023, Irfan i et al., 2019, Rezaei et al., 2018). Other studies have emphasized the role of LPI in explaining economic development (Hausman et al., 2013, Bensassi et al., 2015, Abara, 2021, Song and Lee, 2022, Wang et al., 2024, Mahpour et al., 2023, Turna, 2024) and transport efficiency (Beaudoin et al., 2015, Li et al., 2017, Georgatzi et al., 2020).

Another important indicator is the LSCI, which has been linked in the literature to transportation costs (Wilmsmeier et al., 2006), port infrastructure (Wilmsmeier and Hoffmann, 2008), international trade (Hoffmann, 2005, Atacan et al., 2022), and trade openness (Huong et al., 2024, Wang et al., 2024).

Beyond LPI and LSCI, studies have investigated the determinants of freight transport in different modes. For example, Özen et al. (2020) analyzed factors affecting highway capacity utilization, Jakovljević et al. (2025)

grouped highway transport drivers into economy, population (POP), and traffic-related categories, and Açık and Atacan (2024) examined network connectivity convergence in relation to LSCI, GDP, and trade volume. Similarly, maritime transport has been associated with economic drivers, foreign trade, and transportation costs (Kara and Ciğercioğlu, 2018, Michail et al., 2021, Açık et al., 2019, Atacan et al., 2022), while railway transport has been evaluated from perspectives such as efficiency, demand, ecology, and financial sustainability (Wang et al., 2023, Zhang and Xiang, 2022, Guan and Hu, 2023, Čižiūnienė, 2024, Yang et al., 2022, Wu et al., 2023, Li and Yang, 2023, GyuBae, 2023, Zhao et al., 2024). Finally, air transport has been studied in terms of economic growth (Xiangwei et al., 2023), demand (Wang and Fu, 2022), health services (Thomas et al., 2024), and ecological effects (Shaw et al., 2022).

Conceptual Framework

The process of evaluating logistics performance should be viewed as a complex decision problem characterized by conflicting interests and multiple interconnectedness levels. For example, the planned resource allocation for each mode of transportation cannot be expected to be equal. Monitoring the long-term consequences of different investment decisions is challenging. Such complexities must be modeled to provide policymakers with reliable insights. Various simulation approaches, particularly the SD approach, are effective tools for monitoring the effects of changing factors in real time (Forrester, 1996, Sterman, 2000).

Simulation modeling with system dynamics has found application in many areas, from supply chain analysis (Liu et al., 2023), inventory management (Pierreval et al., 2007, Yeğengil et al., 2011), demand forecasting (Campuzano et al., 2010), capacity planning (Georgiadis et al., 2005), disaster logistics (Peng and Cheng, 2014), solution of supplier selection problems (Orji and Wei, 2015), and sustainable urban logistics applications (Andruetto et al., 2024). In addition, it has become an effective tool in decarbonization and green logistics (Abduaziz et al., 2014, Geng et al., 2017, Menezes et al., 2017, Ghisolfi et al., 2024, Nassar et al., 2023) and container capacity policy planning (Bahadır and Akdağ, 2019).

Overall, the literature has examined the relationship between logistics performance and economic growth in a one-way manner and found a significant relationship between these factors (Nasreen et al., 2018; Ghannouchi et al., 2021; Ghannouchi et al., 2023; Tong and Yu, 2018). Limited research has empirically addressed dynamic variables, such as LPI, GDP, and trade indicators (Jouili, 2019; Hong et al., 2011 Meşin and Cura, 2022). Unlike these studies, the present study simultaneously models the effects of GDP and LSCI on air cargo, the combined impact of foreign trade and LPI on LSCI, and the relationship between GDP, investment, and railway freight, thereby providing a novel contribution to the literature on logistics. In the literature, macroeconomic trends, such as GDP growth, inflation, trade openness, and urbanization, are also evaluated as significant dimensions in the development of the logistics sector (Özer et al., 2021, Zhou et al., 2022, Balkan et al., 2023, Sardarabady et al., 2024, Ohakwe, 2025). Infrastructure is another crucial dimension. Logistics performance is largely influenced by infrastructure quality and improvement, and the infrastructure indicators included in the LPI index play a decisive role in foreign trade volume (Gani, 2017; Abara, 2021; Mahpour, 2023). Furthermore, many studies examining the relationship between logistics dynamics and trade volume have demonstrated a strong mutual interdependence between these two elements (Gani, 2017; Munim and Schramm, 2018, Özer et al., 2021; Zhou et al., 2022; Sardarabady et al., 2024).

To quantitatively represent the dynamics of the logistics sector and use them in the model, we explain the commonly used variables across three main dimensions: trade volume, economic activity, and infrastructure quality. The quantitative indicators of these three main dimensions used to analyze the dynamics of the logistics sector are classified in the literature as follows: Trade volume is represented by imports of goods and services, exports of goods and services, and foreign trade (Marti et al., 2014, Martí et al., 2015; Munim ve Schramm, 2018; Yu and Solis, 2019, Özer et. al 2021, Wang, 2024). Economic activity includes POP, employment (persons) in transportation and storage, investment expenditures (INVE), GDP, and the logistic performance index (LPI) (Zhou et. al.,, 2022, Sardarabady et. al., 2023, Balkan et. al., 2023), and infrastructure quality is reflected in highway investment expenditures (HIEX), freight transport amount on railway, freight transport amount on road, total amount of cargo handled in ports, total freight by airway, and LSCI (Chen and Hasan, 2023, Durmaz and Açık, 2024, Alotaibi et al., 2024).

Building on this literature, the conceptual framework of this study assumes that dynamic interactions among economic, social, and infrastructural factors shape logistics development. Foreign trade, infrastructure investments, and logistics performance are interdependent components that reinforce each other through feedback loops. As highlighted in the literature, the direct and indirect relationships among these factors, such as economic development and investment decisions, should be analyzed across different dimensions. Traditionally, econometric models have been employed to determine causal relationships and measure their strength. However, econometric approaches face limitations when addressing complex systems, as they rely on strict regression assumptions and long time series data (Greene, 2018; Stermna, 1984). In contrast, system dynamics provides a methodological basis for modeling complex relationships by emphasizing causal links, stock–flow structures, and feedback mechanisms rather than static correlations (Barlas, 1996; Sterman, 2000; Morecroft, 2007; Forrester, 1961).

Within this framework, the study considers foreign trade and investment decisions as the primary drivers of Turkiye's logistics capacity development, while logistics performance acts both as an outcome and a reinforcing mechanism. This approach allows the simulation of alternative scenarios and assessment of their implications for different modes of transport.

Methodology

The System and Simulation Approach

System thinking allows real-life problems to be viewed as structures that interact and serve the same goal without separating different factors. The logistics system is a complex structure involving different modes, which are interchangeable and intermodal in many cases, with different dynamics and affected by many economic, social, and environmental factors. Dynamics are generally defined as changes in a system or process over time and the driving force for a system's growth or development (Ghisolfi et al., 2024). Different approaches can be used to model the system dynamics, such as time series modeling, agent-based modeling (ABM), and system dynamics. Econometric models, including time series modeling, are used to predict the future with past data, revealing the short- and long-term interaction between factors.

ABM is one of the most popular modeling and simulation tools for analyzing systems with many interactive agents and emergent system properties. The aggregation process extracts all values. An agent is an encapsulated computational software system that can perceive and act in its environment guided by perceptions and stored information (Abdelshafie et al., 2023). SD allows us to look beyond isolated events and measurements to analyze the dynamic effects in a system and examine the interaction of different parts of the system and how these parts are related over time (Nassar et al., 2023).

Kim (1999) identifies the fundamental characteristics of system dynamics as follows: systems have a purpose; all parts must be present for a system to best achieve its purpose; the order in which the parts are arranged affects the system's performance; and systems attempt to maintain their stability through feedback. The concepts of modeling and simulation are also frequently associated with a system's concept. Models help explain a system, examine the effects of different components, and predict its behavior (Raczynski, 2023). Simulation, on the other hand, provides an explicit and quantitative representation of the entire system to understand its behavior before determining the effects of structures, delays, and policies on system performance (Forrester, 1961). In cases where experimentation with real systems may lead to unpredictable results or excessive costs, simulation emerges as a critical alternative and therefore becomes an important tool for both industry and science (Morcillo et al., 2018).

System dynamics are fundamentally built on feedback loops, stock–flow relationships, and differential equations. The main objective is to simulate the interactions of system components over time and to understand their long-term behavior (Forrester, 1961; Sterman, 2000). Unlike classical econometric models, which rely on strict regression assumptions, such as linearity, homoscedasticity, and normality (Greene, 2018), this approach does not directly depend on such constraints. Since system dynamics focuses less on parameter estimation and more on modeling structural relationships and explaining system behavior through the analysis of feedback mechanisms (Barlas, 1996; Morecroft, 2007). Conversely, in econometric models, having some observations and several variables lead to serious statistical problems. This situation reduces the reliability of parameter estimates, increases the risk of multicollinearity, and limits the model's degrees of freedom (Greene, 2018). In contrast, system dynamics models are based on structural relationships rather than statistical data fitting. Since system behavior is constructed through causal loop diagrams (CLD) and stock–flow structures, having many variables or short time series does not constitute a direct methodological limitation (Forrester, 1961; Sterman, 2000; Barlas, 1996). Nevertheless, this may create certain challenges in parameter calibration and in the model's quantitative validation process (Schwaninger and Groesser, 2020).

System Dynamics

Jay W. At the Massachusetts Institute of Technology (MIT), Forrester pioneered the concept of system dynamics (Hsu, 2012). Forrester (1961) introduced a framework based on four key foundations in his seminal work Industrial Dynamics: the use of digital computers to enable low-cost computation, the application of information feedback theory, the automation of military tactical decision-making, and the experimental modeling of complex systems.

System dynamics is an approach to modeling and analyzing complex systems that is grounded in the principles of systems thinking, mathematics, logic, physics, and the social sciences (Forrester, 1961, 1969, Sterman, 2000, Morecroft, 2007). According to the Society for System Dynamics (SSD, 2024), it is a computer-based method for developing strategies and policies, with the primary aim of supporting more informed decision-making in complex and dynamic systems. The methodology employs simulation modeling based on feedback theory and complements systems thinking approaches. It can be applied across a wide range of domains, including social, economic, ecological, and physiological systems (Amadei, 2015).

In system dynamics, stock and the flows (SFT) that alter them are fundamental concepts. For example, POP increases through births and decreases through deaths, or mercury levels in a child's body rise through food intake and decline through excretion (Sterman, 2006). This approach relies on computer models to explore the interaction of system components, understand system behavior over time, and make future predictions. Appropriate decisions can be made to ensure favorable long-term outcomes once an accurate understanding is achieved, leading to the development and implementation of sound strategies (Mallick, 2023).

Starting from this logic, the system dynamics approach is an effective method for modeling complex problems or relationships to support the development of knowledge of complex logistics behavior. This article highlights how system dynamics can contribute to the knowledge development of complex logistics behavior. Therefore, a system dynamics model approach is applied in this study. The first step in system dynamics application is to create a CLD that formally summarizes the direction and effects of the relationships between factors. This diagram expresses the relationships in the SDA approach (Minegishi and Thiel, 2000). The "+" or "" sign of the arrows on these diagrams indicates the direction of their influence on each other. By multiplying the signs in the loop, the relationships within the whole loop are expressed as reinforcing loops (R) (+) or balancing loops (B) (-). In this method, the factors are connected through differential equations, and the model is completed through transparent and understandable stock and flow diagrams (Shepherd, 2014). In the next step, constructing stock–flow diagrams (SFDs) quantifies causal relationships, defining stock (accumulation) and flow (input-output) structures. This step ensures that the system is grounded in mathematics (Forrester, 1961). Illustrations in the SFD show how stocks and flows are linked in the model. Equation 1 represents the mathematical expression with stock and flow variables. For example, in POP dynamics, births constitute an inflow, whereas deaths constitute an outflow, reducing stocks (Sterman, 2006).

$$Stock\ (x) = t\int_0^t (Inflow(x) - outflow(x))dx + stock(x_0)$$

In system dynamics applications, the modeling process begins with the construction of differential and difference equations to represent the system, which are then transferred into a computer environment for dynamic simulation (Sterman, 2000). In the literature on system dynamics, the variables that explain the overall system behavior are categorized as follows. Endogenous variables are structural elements of the model determined within the feedback loops of the system, which change over time through mutual interactions (Forrester, 1961; Sterman, 2000). For example, other factors influence GDP, foreign trade, employment, and infrastructure investments, while these variables simultaneously shape system behavior. In contrast, exogenous variables are determined outside the model and influence the system but are not generated by its feedback structures. Macroindicators such as population growth or gross domestic product (GDP) growth typically fall into this category and are included in the model as parameters or external shocks (Sterman, 2014, Morecroft, 2007). The model's reliability is then assessed through comparisons with historical data, sensitivity analyses, and validity tests (Morecroft, 2007). Subsequently, policy and scenario experiments are conducted to examine the long-term effects of alternatives on system behavior (Sterman, 2014). Finally, the findings are used to deepen the understanding of system behavior and provide strategic recommendations for decision-makers.

The analysis programs used in this study are Eviews and AnyLogic. EViews was used to quantitatively demonstrate the relationships between variables. Additionally, AnyLogic was used to model the study's system dynamics structure. This platform created causal feedback loops, conducted simulations, and observed the system's dynamic behavior under different scenarios.

Case Study

4.1. Model Structure

Figure 1 shows the structure of the logistics development and planning model created for the research and the methodological approach followed in the study. In this step, the factors affecting logistics capacity development were investigated and determined with a wide literature review. The logistics sector dynamics are addressed multidimensional. The World Bank's LPI 2023 report revealed that trade volume, economic activity, and infrastructure quality are closely related to logistics performance, and for the first time, it included speed indicators measured through big data (World Bank, 2023). Here, endogenous variables are those determined by the model's own dynamics, meaning they interact with each other and their outcomes are reflected within the system. or example, other factors influence GDP, foreign trade, employment, or infrastructure investments, while these variables also directly shape the system's outputs. Exogenous variables (determined outside the model) affect system behavior but are not explained by the model itself. For instance, the population growth rate or GDP growth rate are macro indicators used as parameters or external shocks in the model.

Figure 1

Flow Chart of Model

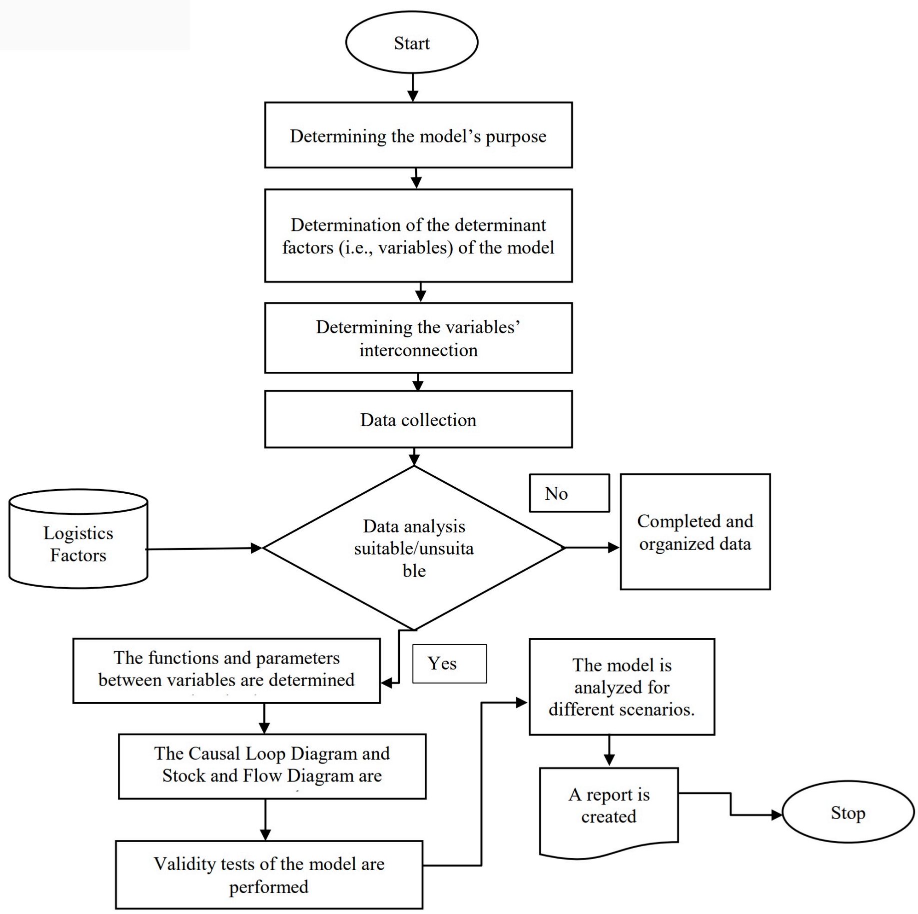


Figure 2

Causal loop diagram

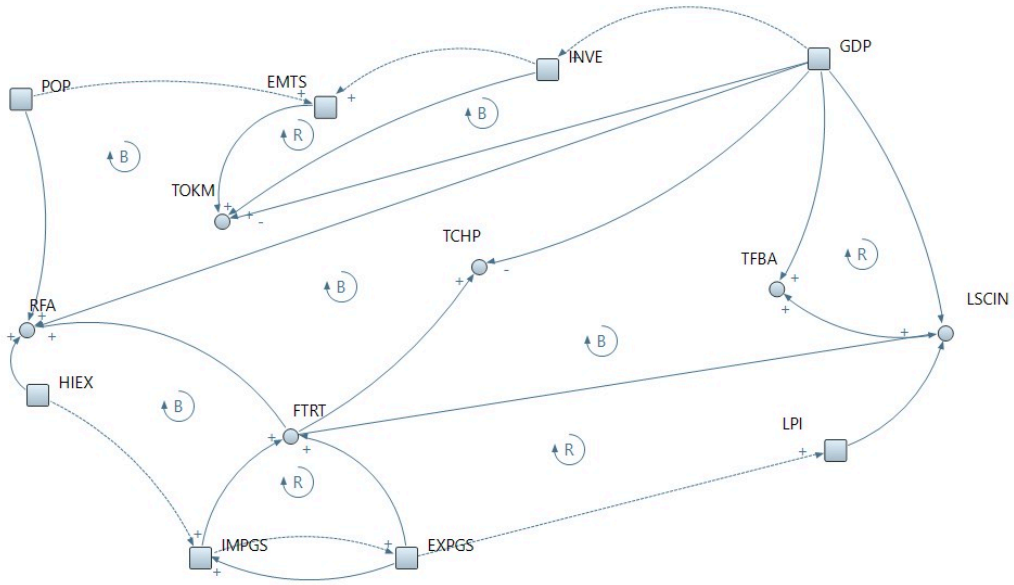


Table 3.

Factors affecting the functioning of the logistics system

Group	Nomenclature	Status	Description	Unit	Data Source
Stock	POP	Endogenous	Population	Thousand (end of the year)	WB
Stock	HIEX	Endogenous	Highway investment expenditures	TL	MTIDDH
Stock	EMTS	Endogenous	Employment (persons) in transportation and storage	Person	TSI
Stock	INVE	Endogenous	Investment expenditures	Thousand TL	CBRT
Stock	GDP	Endogenous	Gross domestic product (GDP)	Current US$	WB
Stock	IMPGS	Endogenous	Imports of Goods and Services	Current US$	WB
Stock	EXPGS	Endogenous	Exports of goods and services	Current US$	WB
Stock	LPI	Endogenous	Logistic performance index	scale 1-5	WB
Convert	RFA	Endogenous	freight transport amount on railroad	Tonne (Thousand)	TSI
Convert	TOKM	Endogenous	amount of freight transported on road	Million	TSI
Convert	TCHP	Endogenous	Total cargo volume handled in ports	tonne	RTMTI
Convert	TFBA	Endogenous	Total Freight by Airway	Tonne	WB
Convert	LSCIN	Endogenous	Liner shipping connectivity index (maximum value in 2004 = 100)		WB

The dataset used for tick variables in the SD model stocks annual time series data for Turkiye between 2002 and 2023. In this study, multi-linear regression analysis methods were used to model factor effects. A regression analysis refers to a set of methods for modeling numerical data. A regression model consists of a defined relationship between the dependent (observed or response) variable and one or more independent (explanatory) variables (Shi and Conrad, 2009). In our study, logarithms of time series were taken to determine the elasticity of variables for estimation models (Gujarati, 2004). Thus, the variance of a series is stabilized (Lütkepohl and Xu, 2012). Table 4 presents the descriptive statistics of logarithmic forms of time series data that enable the establishment of mathematical models of relationships in the model.

Table 4.

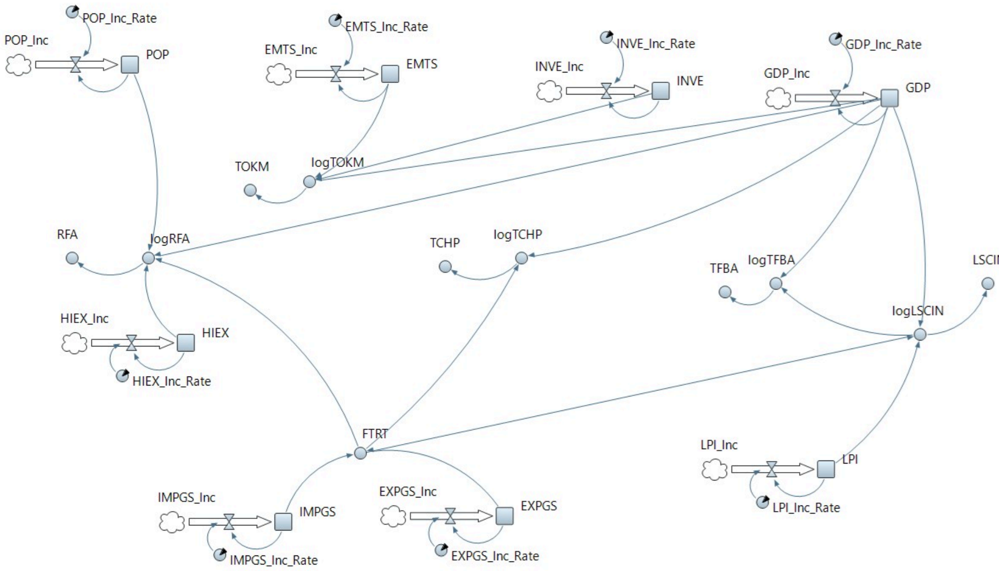
Descriptive statistics of the dataset

	LOG EXPGS	LOG FRTR	LOG GDP	LOGHIEX	LOG IMPGS	LOG INVE	LOG LPI	LOG LSCIN	LOG POP	LOG RFA	LOG TCHP	LOG TFBA	LOG TOKM	LOG EMTS
Mean	11.25	11.58	11.80	10.02	11.29	7.77	0.51	1.66	4.88	4.41	8.55	6.35	5.34	6.07
Median	11.31	11.65	11.89	10.03	11.36	7.76	0.50	1.71	4.88	4.41	8.58	6.37	5.34	6.07
Maximum	11.55	11.87	12.05	11.14	11.59	8.91	0.55	1.80	4.93	4.59	8.73	6.65	5.53	6.23
Minimum	10.78	11.06	11.38	9.20	10.74	7.11	0.50	1.50	4.82	4.20	8.26	5.94	5.18	5.75
Std. Dev.	0.00	0.21	0.16	0.50	0.21	0.48	0.02	0.11	0.04	0.11	0.15	0.22	0.11	0.14
Skewness	−0.79	−0.97	−1.51	0.26	−1.10	0.54	0.81	−0.24	−0.09	−0.12	−0.60	−0.37	0.11	−0.43
Kurtosis	3.11	3.47	4.58	2.77	3.77	2.84	1.83	1.37	1.69	2.20	2.16	1.98	1.83	2.02
Jarque-Bera	2.29	3.65	10.65	0.30	5.01	1.11	3.67	2.66	1.60	0.65	1.96	1.46	1.29	1.55
Probability	0.32	0.62	0.00	0.86	0.08	0.58	0.16	0.26	0.45	0.72	0.38	0.48	0.52	0.46
Sum	247.59	254.66	260.55	220.38	248.45	171.04	11.27	36.55	107.37	96.92	188.06	139.63	117.46	132.00
Sum Sq. Dev.	0.85	0.89	0.56	5.22	0.94	4.80	0.01	0.26	0.03	0.26	0.46	0.98	0.25	0.43
Observatios	22	22	22	22	22	22	22	22	22	22	22	22	22	22

Based on CLD, the model is further elaborated with the stock and flow diagram (Figure 3). The model aims to monitor the effects of dynamic changes in different macrovariables on Turkiye's logistics development and to transform these effects into a resource for policymakers. Table 3 presents the explanations of the factors or variables whose abbreviations are given in Figure 3. For example, as explained in Table 3, "pop_inc_rate" is a dynamic and exogenous variable. The value of this variable is determined within the SDM.

In this study, we obtained the strength of interactions among most factors forming the model framework by constructing econometric models. In system dynamics models, the role of historical data in regression models and econometric models based on time series data must be reviewed. Usually, only the first part of the available data is used to estimate the parameters of a model. Within the fitting period, the R2, t-statistics, and other usual goodness of fit and significance measures can be evaluated. The model is then simulated beyond the fitting period to produce an ex post estimate. Simulating the model beyond the available data produces an ex ante estimate (Pindyck and Rubinfeld, 1976).

Figure 3
Stock and flow diagram



Model overview

The research model does not incorporate all relationships between the factors related to the transportation and logistics sector identified in the literature review. Such a broad scope risks producing a model that is too complex to effectively manage. Therefore, simplifying approaches were applied to address this problem. The model aims to reveal the effects of the key determinants of Turkiye's logistics and transportation potential in the most explanatory form.

After the model was constructed, logistics performance development, the study's central focus, was monitored under different scenarios (Table 5). These scenarios were designed to examine the effects of economic indicator changes and the dynamic evolution of different modes. The efficiency of the SD model was assessed (Table 6), and the input changes' outputs were evaluated (Table 7). The most effective scenarios and influencing factors were identified and discussed based on these outputs.

The assumption of a 5% increase in the scenarios was intended to reflect realistic and incremental changes in logistics infrastructure. Logistics dynamics developments, such as road network expansion, require strategic planning and long-term investment decisions. Thus, assuming a sudden increase of 10% or more in the short term is unrealistic. Incremental changes of approximately 5% represent more feasible improvements that are realistically achievable within a policy planning horizon. This approach allows the model to capture realistic dynamics while providing more accurate assessment of long-term impacts to policymakers. Only the LPI index was tested with a 10% increase, in line with the target of Turkiye.

Table 5.

Description of the scenarios

Scenario	Description
Scenario 1	Simulation results of the model created for 2035
Scenario 2	Simulation results of the model for 2035 if the growth rate of imports increases by 5%
Scenario 3	Simulation results of the model for 2035 if the growth rate of exports increases by 5%
Scenario 4	Simulation results of the model for 2035 if the GDP growth rate (2023 rate) is 5%
Scenario 5	Simulation results of the model for 2035 if the investment growth rate increases by 5%
Scenario 6	Simulation results of the model for 2035 in case the growth rate of highway investment increases by 5%
Scenario 7	Simulation results of the model for 2035 if the LPI growth rate increases by 10%

Table 6 shows the effectiveness of the SD model. The predictive power of the proposed system dynamics model was determined by running the model for 2023, and the results were compared with the actual data for 2023. As shown in Table 6, the RFA TOKM, TCHP, TFBA, and LSCIN variables—namely, freight transport amount on railway, freight transport amount on road, total amount of cargo handled in ports, total freight by air, and liner shipping connectivity index values—have very little deviation from the actual values in the 2023 base year. For example, the mean absolute percentage error (MAPE) of 8% was achieved for the RFA variable. This deviation represents an acceptable result for the forecast models.

Table 6.

Simulation model effectiveness

Situation	Year	RFA	TOKM	TCHP	TFBA	LSCIN
Real	2023	32401	335126	521079804	4447685	62.8
Model	2023	35249	387191	755450438	6785858	83.6
	Error	2848	52065	234370634	2338173	-20,8
MAPE (%)		**0,088**	**0,155**	**0,450**	**0,526**	**0,331**

The logistics performance development outcomes for Turkiye in different scenarios are presented in Table 7. The low deviation values (MAPE) of the proposed system dynamics model indicate that the model is reliable. Table 5 shows the effects of changes in input variables (e.g., a 5% increase) and output variables for the seven scenarios proposed. First, the proposed system dynamics model was run for 2035, and then the effects of a 5% increase in the import growth rate, export growth rate, GDP growth rate, investment growth rate, highway growth rate, and LPI growth rates in 2035 were monitored (Table 7).

Table 7.

Scenario Results of the Model

Scenario (Year 2035)	RFA (tonne (thousand)	TOKM (Million)	TCHP (Tonne)	TFBA (Tonne)	LSCIN
Scenario 1	55244.150	646999.630	1746744446.816	20912385.718	144.724
Scenario 2	60619.599	656877.474	2010447029.605	26130816.667	167.615
Scenario 3	57951.314	646991.630	1872733403.342	23436024.641	156.570
Scenario 4	52737.012	648993.069	1705631356.581	18846663.482	129.156

Scenario (Year 2035)	RFA (tonne (thousand)	TOKM (Million)	TCHP (Tonne)	TFBA (Tonne)	LSCIN
Scenario 5	56738.237	693236.204	1835826960.226	22357675.164	149.519
Scenario 6	53821.556	655456.016	1784393209.358	21519888.710	146.750
Scenario 7	53227.475	646991.630	1746744460.816	21735030.739	148.625

The relationships between variables were estimated using econometric models in constructing the system dynamics model. For each variable, a forecasting model was developed, and the system dynamics model was built upon this framework. Table 8 shows the MAPE values of the models used to measure the predictive power of these relationships. For example, the regression equation used in the RFA estimation had a deviation of 0.26 %. Based on these results, an excellent prediction was made with a variance of about MAPE results between 0.2% and 2%. Less than 10% MAPE value is considered as highly accurate forecast value (Lewis, 1982). Therefore, the predictive power of the models established from these MAPE results is quite strong.

Table 8.

MAPE results in terms of the model factors

Nomenclature	Name	Formula	MAPE
RFA	Freight transport amount on railroad	logRFA = 2.25*logPOP + 0.69*logFRTR 0.46*logGDP 0.087*logHIEX +8.164	0,26%
TOKM	Freight transport amount on the road	logTOKM = −0.13*logGDP + 0.095*logINVE + 0.557*logEMTS + 2.79	0,20%
TCHP	Total cargo volume handled in ports	logTCHP = −0.49*logGDP + 0.999*logFRTR + 1.94	0,46%
TFBA	Total Freight by Airway	logTFBA = 1.45*logLSCIN + 0.33*logGDP	0,70%
LSCIN	Liner shipping connectivity index (maximum value in 2004 = 100)	logLSCIN = 1.999 logLPI 0.98 logGDP + 1.18 logFRTR 0.96	1,70%

Discussion and Conclusions

This study develops an SD model to represent the Turkish logistics system's dynamic conditions. Subsequently, the proposed model was extended with retrofit solutions aligned with seven different policy decisions, and these solutions were simulated under various scenarios. The simulation results are presented to support decision-makers in selecting appropriate and feasible strategies.

This study addresses three main research questions. First, it investigates how models developed under uncertainty regarding causal parameters and system structure can support policymakers' decision-making. The problem is modeled using a systems approach that incorporates uncertainties influencing a country's logistics performance and development, particularly uncertainties related to key economic indicators, with all statistically significant connections included in the model. The factors affecting logistics performance development are identified and explained through a comprehensive literature review and expert consultations.

Second, the study examines how interventions and planning adjustments affect system efficiency, underlying assumptions, and outputs. For this purpose, different scenarios were constructed and their results were monitored through the model in the form of a cause–effect structure.

Finally, the study derives efficiency rankings for the scenario changes based on the model outputs. Table 9 presents the study results. These results can be interpreted as follows:

Table 9.

Impact matrix for factors

Factors →	Rail	Road	Port	Air	LSCI
Imports	***	***	***	***	***
Exports	***	***	***	***	***
Investment	***	***	***	***	**
Road Investment	***	***	***	***	**
LSCI	***	***	***	***	❌ (self-variable)
GDP	***	***	***	***	***
*** = high impact		** = medium impact		* =low impact	

1) In a country such as Turkiye, which aims to become a logistics hub between Europe and Asia, monitoring the development of the logistics sector through diverse dynamics is strategically important. The proposed SD model visualizes the impact of changes in these dynamics on the system over time and provides an effective monitoring and evaluation tool for policymakers. Therefore, the proposed system dynamics model contributes to decision support systems by revealing the interactions between logistics system components.

(2) The macroeconomic indicators and logistics components are the key components that increase the efficiency of rail transport in Turkiye. The findings indicate that the increase in imports, exports, investment, road investment, LSCI, and GDP are the key factors affecting the effectiveness of rail transport development strategies within Türkiye's logistics system. This result demonstrates that economic growth and the expansion of foreign trade improve rail transport, while the integrated development of modes is supported by the increase in logistics dependence.

(3) Increases in investment, imports, road investment, gross domestic product (GDP), exports, and LSCI have been identified as the key factors affecting the effectiveness of road transport development strategies within Türkiye's logistics system. The findings indicate that roads continue to be the backbone of Turkiye's logistics system, and infrastructure investments play a supporting role as economic activity increases road freight demand.

(4) Increases in imports, exports, investment, road investment, LSCI, and GDP influence the effectiveness of development strategies for cargo volume handled at ports. This result demonstrates that port activities are a sensitive indicator of both economic growth and integration into IL (International logistics) networks. As trade volume expands and the connectivity index improves, ports handle higher traffic and gain a stronger strategic position.

(5) Increases in imports, exports, investment, LSCI, road investment, and gross domestic product (GDP) have been identified as the key factors affecting the effectiveness of air transport development strategies within Türkiye's logistics system. This finding indicates that air transportation is assuming an increasingly critical role in Turkiye's high-value-added trade structure and integration into global supply chains.

(6) Imports, exports, investment, LPI, road investment, and GDP growth were identified as the primary factors affecting LSCI, a critical determinant of LPI. This result demonstrates that international connectivity, economic activity, investment, and infrastructure development act in the same direction, and that Turkiye's level of integration into global supply chains is directly dependent on these variables.

Following the various scenarios examined in this study, the following practical recommendations are made.

(1) Government support is essential for enhancing national logistics performance. Budgetary allocations and improvements in logistics performance indicators can only be achieved with strong government support. For example, custom development, an LPI indicator, is evaluated across multiple dimensions, ranging from digitalization to waiting time reduction. These dimensions can only be effectively implemented if they are integrated into government planning and strategies. Active support from relevant authorities and organizations is required to establish and sustain an effective logistics performance development system.

(2) Foreign trade exerts the strongest influence on Turkiye's logistics capacity performance development, followed by investment decisions. Higher investment levels enhance the use capacities of different transport modes.

This study proposes a dynamic model to monitor logistics performance and development. However, this study remains preliminary and is subject to certain limitations. For Turkiye, the evaluation was restricted to time-series data from 2002 to 2023. Some factors identified through the literature and expert opinions were excluded from the model due to dataset constraints. Moreover, indicators such as the LPI, which are highlighted as important in the literature, contained missing values because they are not published annually. These gaps were addressed using interpolation to render the data suitable for econometric forecasting.

Future research could expand the model within a sustainability framework by incorporating social and environmental dimensions alongside economic ones. The model developed here, while focusing on Turkiye, can also be adapted to other countries and regions. Because it primarily addresses macro-level effects in logistics capacity development, it was established independently of micro-level cost considerations. In the case of Turkiye, cost could be incorporated as a sub-model, particularly given that energy— the most significant cost factor in transportation—remains a critical issue for an energy-dependent country. Finally, policymakers should evaluate and discuss the feasibility of policy scenarios derived from the model.

Peer Review: Externally peer-reviewed.
Conflict of Interest: The author have no conflict of interest to declare.
Grant Support: The author declared that this study has received no financial support.

Author Details
Özlem Karadağ Albayrak
[1] Kafkas University, Faculty of Economics and Administrative Sciences,Department of International Trade and Logistics Department, Kars, Türkiye
0000-0003-0832-0490 ozlemkaradagalbayrak@gmail.com

References

Abara, Y. (2021). The impact of logistics performance on foreign trade volume, J. Ind. Policy Technol. Manag., 4(2), 133-144

Abdelshafie A, Rupnik B, Kramberger T. 2023. Simulated Global Empty Containers Repositioning Using Agent-Based Modeling. *Systems*, 11(3), 130. https://doi.org/10.3390/systems11030130

Abduaziz, O., Cheng, J. K., Tahar, R. M. and Varma, R. (2015). Hybrid simulation model for green logistics assessment in the automotive industry *Procedia Engineering*, 100, 960-969. https://doi.org/10.1016/j.proeng.2015.01.455

Acık, A., & Atacan, C. (2024). Analyzing the convergence of transport network connectivity: The case of Turkiye and its neighbors *Oasis*, (39), 189-212. https://doi.org/10.18601/16577558.n39.11.

Acık, A., Sağlam, B. B., & Kayıran, B. (2019). Industrial production as a leading indicator of container port throughput in Turkey *Dokuz Eylül Üniversitesi Denizcilik Fakültesi Dergisi*, 11(1), 37-56. https://doi.org/10.18613/deudfd.614828https://doi.org/10.18613/deudfd.614828

Andruetto C, Stenemo, E., & Pernestål, A. (2024). Toward sustainable urban logistics: Exploring the implementation of city hubs through system dynamics. *Transportation Research Interdisciplinary Perspectives*, 27, 101204. https://doi.org/10.1016/j.trip.2024.101204

Arman, K., & Organ, A. (2023). Evaluation of the Logistics Performances of EU Member and Candidate Countries with MEREC and CoCoSo, *Uluslararası Ticaret ve Ekonomi Araştırmaları Dergisi* 7(2), 36-46. https://doi.org/10.30711/utead.1360959

Atacan, C., Kayıran, B., & Açık, A. (2022). Impact of liner shipping connectivity on container traffic in Turkish ports *Transactions on Maritime Science*, 11(02), 2-2. doi: 10.7225/toms.v11.n02.w01

Alotaibi, S., Quddus, M., Morton, C., & Imprialou, M. (2022). Transport investment, railway accessibility, and their impact on regional economic growth. *Research in Transportation Business & Management*, 43, 100702. DOI: 10.1016/j.rtbm.2021.100702

Bahadir, M. C., & Akdag, H. C. (2019). System dynamics modeling for container capacity and transportation planning policies *The Asian Journal of Shipping and Logistics*, 35(4), 200-212. https://doi.org/10.1016/j.ajsl.2019.12.007

Barlas, Y. (1996). The formal aspects of model validity and validation in the context of system dynamics. *System Dynamics Review: The Journal of the System Dynamics Society*, Vol. 12, No. 3, pp. 183-210.

Bensassi S, Márquez-Ramos, L., Martínez-Zarzoso I, Suárez-Burguet C. 2015. Relationship between logistics infrastructure and trade: Evidence from regional exports in Spain *Transportation Research Part A: Policy and Practice*, 72, 47-61. https://doi.org/10.1016/j.tra.2014.11.007

Beaudoin, J., Farzin, Y. H., & Lawell, C.-Y. (2015). Public transit investment and sustainable transportation: A review of studies on the impact of transit on traffic congestion and air quality *Research in Transportation Economics*, 52, 15–22. https://doi.org/10.1016/j.retrec. 2015.10.004

Bi, Y., the Yuan, H., & Chang, S. H. (2020). Dynamic correlation analysis of regional logistics from the multifractal feature perspective *Fractals*, 28(08), 2040015. https://doi.org/10.1142/S0218348X20400150

Bugarčić, F. Ž., Mićić, V., & Stanišić, N. (2023). Role of logistics in economic growth and global competitiveness *Zbornik Radova Ekonomski Fakultet u Rijeka,* 41(2), 499-520. https://doi.org/10.18045/zbefri.2023.2.499

Campuzano, F., Mula, J., & Peidro, D. (2010). Fuzzy estimations and system dynamics for supply chain improvement. *Fuzzy Sets and Systems*, 161(11), 1530-1542. https://doi.org/10.1016/j.fss.2009.12.002

Castaneda, J., Ghorbani, E., Ammouriova, M., Panadero, J., and Juan, A. A. (2022). Optimizing transport logistics under uncertainty with simheuristics: Concepts, review and trends. *Logistics*, 6(3), 42. https://doi.org/10.3390/logistics6030042

Čižiūnienė, K., Matijošius, J., Sokolovskij, E., & Balevičiūtė, J. (2024). Assessment of implementing green logistics principles in railway transport: the case of Lithuania. *Sustainability*, 16(7), 2716. https://doi.org/10.3390/su16072716

Chen, Y. C., & Hasan, M. K. (2023). Impacts of Liner Shipping Connectivity and Global Competitiveness on Logistics Performance: The Mediating Role of Port and Infrastructure Quality *Journal of Shipping and Trade*, 8(1), 18. https://doi.org/10.1186/s41072-023-00152-4

Durmaz, A., & Açık, Ö. (2024). Determining the growth drivers in container shipping *Acta Natura et Scientia*, 5(2), 136–149. DOI: 10.61326/actanatsci.v5i2.287

Forrester, J. (1958). Industrial Dynamics: A breakthrough for decision-makers *Harvard Business Review*. 35(4): 37. 66.

Forrester, J. W. (1961). Industrial dynamics. MIT Press.

Forrester, W. (1969). Urban Dynamics, MIT Press.

Fugazza, M. and Hoffmann, J. (2017). Liner Shipping Connectivity as Determinant of Trade. *Journal of Shipping and Trade, 2(1), 1. doi: 10.1186/s41072-017-0019-5*

Gani, A. 2017. The effect of logistics performance in international trade. The Asian Journal of Shipping and Logistics, 33(4), 279–288. https://doi.org/10.1016/j.ajsl.2017.12.012

Geng X, Wen Y, Zhou C, Xiao C. 2017. Establishing a sustainable ecosystem for the regional shipping industry based on system dynamics. Sustainability, 9(5), 742. https://doi.org/10.3390/su9050742

Georgatzi, V. V., Stamboulis, Y., & Vetsikas, A. (2020). Examining the determinants of CO2 emissions from the transport sector: Empirical evidence from 12 European countries *Economic Analysis and Policy*, 65, 11–20. https://doi.org/10.1016/j.eap.2019.11.003

Georgiadis, P., Vlachos, D., & Iakovou, E. (2005). A system dynamics modeling framework for food chain strategic supply chain management *Journal of food engineering*, 70(3), 351-364. DOI: 10.1016/j.jfoodeng.2004.06.030

Ghannouchi, I., Ouni, F., & Aloulou, F. (2023). Investigating the impact of transportation system and economic growth on carbon emissions: Application of the Global Minimum Minimum (GMM) System for 33 European countries Environmental Science and Pollution Research, 30(39), 90656-90674. https://doi.org/10.1007/s11356-023-28595-6

Ghisolfi, V., Tavasszy, L. A., Correia, G. H. D. A. R., Chaves, G. D. L. D., & Ribeiro, G. M. (2024). Dynamics of decarbonization of freight transport: A simulation study for Brazil *Transportation Research Part D: Transport and Environment*, 127, 104020. https://doi.org/10.1016/j.trd.2023.104020

Górniak, J. (2022). Selected Logistics Development Level Indicators in European Union Countries: A Review and Comparative Analysis Comparative economic research *Central and Eastern Europe*, 25(1), 127-144. https://doi.org/10.18778/1508-2008.25.08

Greene, W. H. (2018). Econometric analysis (8th ed.). New York: Pearson, 2001.

Guan, C., & Hu, Q. (2023). Does high-speed railways impact the agglomeration of the urban logistics industry? Empirical evidence from China's prefecture-level cities. *Socio-Economic Planning Sciences*, 87, 101557. https://doi.org/10.1016/j.seps.2023.101557

Gujarati, D. N., 2004. Basic Econometrics, 4th Edition. USA: Tata McGraw Hill; 2004.

Gürler, H. E., Özçalıcı, M., & Pamucar, D. (2024). Determining criteria weights with genetic algorithms for multi-criteria decision making methods: The case of logistics performance index rankings of European Union countries. *Socio-Economic Planning Sciences*, 91, 101758. https://doi.org/10.1016/j.seps.2023.101758

GyuBae, K. I. M. (2023). Development of Railway Logistics Business Model and Track Capacity *Journal of Distribution Science*, 21(9), 93-102.

Hausman, W. H., H. L. Lee, and U. Subramanian. 2013. Impact of logistics performance on trade. *Production and Operations Management*, 22(2), 236-252. https://doi.org/10.1111/j.1937-5956.2011.01312.xhttps://doi.org/10.1111/j.1937-5956.2011.01312.x

Hong, J., Chu, Z. and Wang, Q. (2011). Transport infrastructure and regional economic growth: evidence from China. *Transportation*, 38, 737-752. https://doi.org/10.1007/s11116-011-9349-6

Hoffmann, J. (2005). Liner Shipping Connectivity. *UNCTAD Transport Newsletter*, 27(1): 4-12.

Hsu, C. W. (2012). A system dynamics model was used to assess the effects of capital subsidies and feed-in tariffs on solar PV installations. *Appl Energy*, 100(Supplement C):205–217. DOI: 10.1016/j.apenergy.2012.02.039

Huong VTT, Van Kiem P, Thuy NT, Trang VTH, Ha HTT (2024). Assessing the impact of green logistics performance on Vietnam's export trade to regional comprehensive economic partnership countries. *Int. J. Innovative Res Sci Stud*, 7(2):742–754

Irfani, D. P., Wibisono, D., & Basri, M. H. (2019). A logistics performance management system based on the system dynamics model is designed. *Measuring Business Excellence*, 23(3), 269-291. https://doi.org/10.1108/MBE-01-2019-0008

Jakovljević, M., Vertlberg, J. L., Šoštarić, M., & Ševrović, M. (2025). Determination of Factors Influencing Demand for Road Transport: Evidence from Croatia *Applied Sciences*, 15(4), 2238. https://doi.org/10.3390/app15042238

Jifeng, W. A. N. G., Huapu, L. U., & Hu, P. E. N. G. (2008). The system dynamics model of the urban transportation system and its application. *Journal of Transportation Systems Engineering and Information Technology*, 8(3), 83-89. https://doi.org/10.1016/S1570-6672(08)60027-6https://doi.org/10.1016/S1570-6672(08)60027-6

Jouili, T. A. (2019). Determinants of the connectivity of liner shipping *International Journal of Advanced and Applied Sciences*, 6, 5-10. https://doi.org/10.21833/ijaas.2019.11.002

Kale, M. V., & Tilki, İ. (2024). Dünya ülkelerinin lojistik performanslarının çok kriterli karar verme yöntemi ile değerlendirilmesi: 2023 Yılı dünya bankası raporu ile karşılaştırmalı analizi. *Dumlupınar Üniversitesi Sosyal Bilimler Dergisi*, (80), 13-30. https://doi.org/10.51290/dpusbe.1387317

Kara, M. A., & Ciğerlioğlu, O. (2018). Turkiye ekonomisinde ulaşım altyapısının ekonomik büyümeye etkisi. *Gaziantep University Journal of Social Sciences*, 17(2), 577-591. https://doi.org/10.21547/jss.382949

Kim, D. H. (1999). Introduction to Systems Thinking. 1999 by Pegasus Communications, Inc. 1999.

Kim S, Kim H. (2016). A new absolute percentage error metric for intermittent demand forecasts *International Journal of Forecasting,* 32(3), 669-679. https://doi.org/10.1016/j.ijforecast.2015.12.003

La, K. W., & Song, J. G. (2019). Empirical study on the effects of export promotion on Korea-China-Japan using the logistics performance index *Journal of Korea Trade*, 23(7), 96-112.

Lewis, C. D. (1982). Industrial and business forecasting methods: A practical guide to exponential smoothing and curve fitting, London; Boston: Butterworth Scientific.

Li, J., Zhai, J., Chen, Y., Liu, S., 2010. System Dynamic Simulation Approach for Supply Chain with Capability, *Limit. J. Comput*, 5(7), 1125-1132. https://doi.org/10.4304/jcp.5.7.1125-1132

Li, W., & Yang, S. (2023). High-speed railway-based fast logistics service network design problem. *Modern Physics Letters B*, 37(13), 2350020. https://doi.org/10.1142/S0217984923500203

Li, X., Fan, Y., & Wu, L. (2017). CO2 emissions and expansion of railway, road, airline and in-land waterway networks over the 1985–2013 period in China: A time series analysis. Journal of the National Aeronautics and Space Administration. *Transportation research Part D: Transport and environment*, 57, 130-140. https://doi.org/10.1016/j.trd.2017.09.008https://doi.org/10.1016/j.trd.2017.09.008

Liu, P., Atifeh, M., Khorshidnia, M., & Taheri, S. G. (2023). System dynamics: an approach to supply chain performance measurement modeling *Technological and Economic Development of Economy*, 29(4), 1291-1317. https://doi.org/10.3846/tede.2023.19211

Lütkepohl, H. and Xu, F. (2012). Role of the log transformation in forecasting economic variables *Empirical Economics*, 42, 619-638. https://doi.org/10.1007/s00181-010-0440-1

Mallick, R. B. (2023). System Dynamics for Complex Problems in sidewalk Engineering, Taylor & Francis Group, CRC Press.

Mahpour, A., Farzin, I., Baghestani, A., Ashouri, S., Javadi, Z., and Asgari, L. (2023). Modeling the impact of countries' logistic performance, economic features, and demographic factors on seaborne trade. *The Asian Journal of Shipping and Logistics*, 39(2), 60-66. https://doi.org/10.1016/j.ajsl.2023.02.003

Morcillo, J. D., Franco, C. J., & Angulo, F. (2018). Simulation of demand growth scenarios in the Colombian electricity market: An integration of system dynamics and dynamic systems *Applied Energy*, 216, 504–520. DOI: 10.1016/j.apenergy.2018.02.104

Morecroft, J. D. W. (2007). Strategic modeling and business dynamics: A feedback systems approach. Chichester: John Wiley & Sons.

Martí, L., Puertas, R., & García, L. (2014). Importance of the Logistics Performance Index in International Trade: Evidence from OECD Countries *International Economics*, 139, 99–117. https://doi.org/10.1016/j.inteco.2014.05.002

Martí, L., Puertas, R., & García, L. (2015). Importance of the logistics performance index in international trade: The Spanish case *Transportation Research Part A: Policy and Practice*, 78, 82–93. https://doi.org/10.1016/j.tra.2015.05.006

McKinnon, A. (2012). Environmental sustainability: A new priority for logistics managers In: McKinnon A, Browne M, Whiteing A, editors. Green Logistics: Improving the Environmental Sustainability of Logistic, *Kogan Page Publishers*, 3–10.

Menezes, E., Maia, A. G. and de Carvalho, C. S. (2017). Effectiveness of low-carbon development strategies: Evaluation of policy scenarios for the urban transport sector in a Brazilian megacity *Technological Forecasting and Social Change*, 114, 226-241. https://doi.org/10.1016/j.techfore.2016.08.016

Meşin, K., & Cura, F. (2022). Turkiye Dış Ticaretinin Lojistik Performans Çerçevesinde Değerlendirilmesi. *Sosyal ekonomik araştırmalar dergisi*, 22(2), 139-149. https://doi.org/10.30976/susead.1148908https://doi.org/10.30976/susead.1148908

Michail, N., Melas, K. D., & Batzilis, D. (2021). Container shipping trade and real GDP growth: A panel vector autoregressive approach, *Economics Bulletin*, 41(2). https://dx.doi.org/10.2139/ssrn.3724480

Minegishi, S., & Thiel, D. (2000). Modeling and simulation of system dynamics of a particular food supply chain *Simulation practice and theory,* 8(5), 321-339. https://doi.org/10.1016/S0928-4869(00)00026-4

Mohamad, R., Kamonchanok, S., & Pongsa, P. (2015). Liner shipping connectivity and international trade in maritime Southeast Asian countries *Journal of International Logistics and Trade*, 13(3), 43-74. https://doi.org/10.24006/jilt.2015.13.3.43https://doi.org/10.24006/jilt.2015.13.3.43

Morecroft, J. D. W., 2007. Strategic Modeling and Business Dynamics: A Feedback Systems Approach. Chichester, England; Hoboken, NJ: John Wiley & Sons, Inc

Munim, Z. H., & Schramm, H. J. (2018). Impacts of Port Infrastructure and Logistics Performance on Economic Growth: The Mediating Role of Seaborne Trade *Journal of Shipping and Trade*, 3(1), 1–19. https://doi.org/10.1186/s41072-018-0027-0

Nassar, R. F., Ghisolfi, V., Annema, J. A., van Binsbergen, A., & Tavasszy, L. A. (2023). A system dynamics model for analyzing modal shift policies in freight transportation toward decarbonization. *Research in Transportation Business & Management*, 48, 100966. https://doi.org/10.1016/j.rtbm.2023.100966

Nasreen S, Saidi S, Ozturk I. (2018). Linkages between energy consumption, freight transport, and economic growth: Evidence from dynamic simultaneous equation models *Environmental Science and Pollution Research International*, 25(17), 16825–16841. https://doi.org/10.1007/s11356-018-1760-5

Orji, I. J., & Wei, S. (2015). Innovative integration of fuzzy logic and system dynamics in sustainable supplier selection: A case study on the manufacturing industry *Computers and Industrial Engineering*, 88, 1-12. https://doi.org/10.1016/j.cie.2015.06.019https://doi.org/10.1016/j.cie.2015.06.019

Ohakwe, C. R. (2025). Impact of macroeconomic indicators on logistics performance *Journal of Transport Geography*, 124, 103829. doi: 10.1016/j.jtrangeo.2025.103829

Özen, M., Fayyaz, M., & Yaman, H. T. (2020). Factors affecting capacity utilization of road freight transport in Turkey *Teknik* Dergi, 31(2), 9813-9832. https://doi.org/10.18400/tekderg.413807

Özer, M., Yıldırım, S., & Turan, T. (2021). Impact of Container Transport on Turkey's Economic Growth *Research in Transportation Business & Management*, 41, 100627. DOI: 10.1016/j.rtbm.2020.100627

Peng, M., Peng, Y., & Chen, H. (2014). Post-seismic supply chain risk management: A system dynamics disruption analysis approach for inventory and logistics planning. Journal of Applied Mechanics and Logistics Management, 27(4), e0163. *Computers and Operations Research*, 42, 14-24. https://doi.org/10.1016/j.cor.2013.03.003

Pierreval, H., Bruniaux, R. and Caux, C. (2007). A continuous simulation approach for automotive supply chains *Simulation Modeling Practice and Theory*, 15(2), 185-198. https://doi.org/10.1016/j.simpat.2006.09.019

Pindyck, R., & Rubinfeld, D. (1976). Econometric Models and Economic Forecasts New York: McGraw Hill.

Radzicki, M. J., & Sterman, J. D. (1994). Evolutionary economics and system dynamics *Evolutionary concepts in contemporary economics*, 61-89.

Raczynski, S. (2023). Research and Understanding Models: Exploring Dynamic Systems, Unconventional Approaches, and Applications Springer.

Rezaei, J., Roekel, W. and Tavasszy, L. (2018). Measuring the relative importance of the logistics performance index indicators using best worst method, *Transport Policy*, Vol. 68, September, pp. 158-169. https://doi.org/10.1016/j.tranpol.2018.05.007

Saparovna, M., K., Sarsengalievich, O., S., Antoni, A., & Duzbaievna, S. (2018). Evaluation of the efficiency of railway transport and logistics infrastructure *Pomorstvo*, 32(1), 88-101. https://doi.org/10.31217/p.32.1.3

Sardarabady, N. J., Ahmed, S., & Kumar, R. (2024). A systematic literature review on the logistics sector's economic impact *Case Studies on Transport Policy*, 12(1), 34–49. https://doi.org/10.1016/j.cstp.2023.12.004

Schwaninger M, Groesser S. 2020. System dynamics modeling: Validation for quality assurance. In B. Dangerfield (Ed.), System dynamics (pp. 119–138). Springer. doi: 10.1007/978-1-4939-8790-0_540

Sezer S, Abasiz T. 2017. The impact of the logistics industry on economic growth: An application in OECD countries Eurasian *Journal of Social Sciences*, vol. 5, no. 1, pp. 11-23.

Shepherd, S. P. (2014). A review of system dynamics models applied in transportation. *B: Transp. Dynam*. 2 (2), 83–105. https://doi.org/10.1080/21680566.2014.916236

Shafique, M., Azam, A., Rafiq, M., & Luo, X. (2021). Investigating the nexus among transport, economic growth, and environmental degradation: Evidence from panel ARDL approach. *Transport Policy*, 109, 61–71. doi: 10.1016/j.tranpol.2021.04.014

Shaw, B. K., Sangal, I., & Sarkar, B. (2022). Reduction of greenhouse gas emissions in an imperfect production process under breakdown consideration. *AIMS Environ*. Sci, 9, 658-691. https://doi.org/10.3934/environsci.2022038

Shi, R. and Conrad, S. A. (2009). Correlation and regression analysis. Ann Allergy Asthma Immunol, 103(4), S34-S41. DOI: 10.1016/j.tranpol.2021.04.014

Song, M. J., & Lee, H. Y. (2022). The relationship between international trade and logistics performance: A focus on the South Korean industrial sector Research in Transportation Business & Management, 44, 100786. DOI: 10.1016/j.rtbm.2022.100786

Sterman, J. D. (1984). Appropriate summary statistics for evaluating the historical fit of system dynamics models. *Dynamica*, vol. 10, no. 2, 51-66.

Sterman, J. D. (2000). Business dynamics: Systems thinking and modeling for a complex world. Boston: Irwin/McGraw-Hill.

Sterman, J. D. (2001). System dynamics modeling: - tools for learning in a complex world. Calif. Manage. Rev, 43 (4). https://doi.org/10.2307/41166098

Sterman, J. D. (2006). Learning from evidence in a complex world American Journal of Public Health, 96(3), 505-514. https://doi.org/10.2105/AJPH.2005.066043

Sterman, J. D. (2014). System dynamics at sixty : The path forward. System Dynamics Review, 30(1–2), 5–49. DOI: 10.1002/sdr.1601

Stević, Ž., Ersoy, N., Başar, E. E., & Baydaş, M. (2024). Addressing the Global Logistics Performance Index Rankings with Methodological Insights and an Innovative Decision Support Framework *Applied Sciences*, 14(22), 10334.

J. Thomas, R. Crowe, K. Schulz, H. E. Wang, M. C. D. O. Otto, B. Karfunkle, Huebinger, R. (2024). Association between the intubation rate and intubation success of emergency medical service agenciesemergency medical service agency intubation rate and intubation success. *Annals of Emergency Medicine*, 84(1), 1-8. doi: 10.1016/j.annemergmed.2023.11.005

Tong, T., & Yu, T. E. (2018). Transportation and economic growth in China: A heterogeneous panel co-integration and causality analysis *Journal of Transport Geography*, 73, 120-130. https://doi.org/10.1016/j.jtrangeo.2018.10.016

Turna, Y. (2024). The Impact of Countries' Logistics Performance on Their Exports: The Case of G-8 Countries *Journal of Transportation and Logistics*, 9 (1), 60-67. https://doi.org/10.26650/JTL.2024.1353603

Ülker, T., Eken, E. N., & Bulut, N. (2024). The Impact of Logistic Performance Index and Ease of Doing Business on Trade Volume in Eurasian Countries: A Gravity Model, Internatıonal Congress On Eurasıan Economıes 2024, DOI: 10.36880/C16.02909.

Xiangwei, X. I. E., Jie, P. A. N., Jinjing, Z. H. A. O., & Miao, S. U. (2023). Examining the Economic Effects of Logistics Infrastructure: The Case of the New Western Land-Sea Corridor in China *Journal of Distribution Science*, 21(8), 23-34. https://doi.org/10.15722/jds.21.08.202308.23

Wang, S., & Fu, S. (2022). Path design and planning and investment and construction mode of multimodal transport network based on big data analysis. *Discrete Dynam. Nat. Soc.*, 2022 (1), 9185372. https://doi.org/10.1155/2022/9185372

Wang, P., Zhang, Y., & Guo, W. (2023). Demand forecast of railway transportation logistics supply chain based on machine learning model. International *Journal of Information Technologies and Systems Approach (IJITSA)*, 16(3), 1-17. https://doi.org/10.4018/IJITSA.323441

Wang, W., Wu, Q., & Su, J. (2024). The impact of international logistics performance on import and export trade: an empirical case of the "Belt and Road" initiative countries. *Humanities and Social Sciences Communications*, 11(1), 1-10. https://doi.org/10.1057/s41599-024-03541-0

Wang, S. (2024). Impact of international logistics performance on China's imports and exports: An extended gravity model approach *Humanities and Social Sciences Communications*, 11, 301. https://doi.org/10.1057/s41599-024-02946-2

Wilmsmeier, G., Hoffmann, J., & Sanchez, R. J. (2006). The impact of port characteristics on international maritime transport costs. *Research in Transportation Economics*, 16: 117-140. https://doi.org/10.1016/S0739-8859(06)16006-0https://doi.org/10.1016/S0739-8859(06)16006-0

Wilmsmeier, G. and Hoffmann, J. (2008). Liner Shipping Connectivity and Port Infrastructure as Determinants of Freight Rates in the Caribbean *Maritime Economics and Logistics*, 10(1-2): 130-151. https://doi.org/10.1057/palgrave.mel.9100195https://doi.org/10.1057/palgrave.mel.9100195

Wiman, H., Tuominen, A., Mesimäki, J., Penttinen, M., Innamaa, S., & Ylén, P. (2022). System dynamics simulation of transport mode choice transitions under structural and parametric uncertainty. *European transport research review*, 14(1), 40. https://doi.org/10.1186/s12544-022-00564-zhttps://doi.org/10.1186/s12544-022-00564-z

World Bank. (2023). Connecting to Compete 2023: Trade Logistics in the Global Economy: Logistics Performance Index (LPI) and its Indicators Washington, DC: World Bank. Retrieved from https://lpi.worldbank.org

Wu, H., Wang, Y., Zhang, P., Yu, J., & Du, Y. (2023). Research on Partner Selection of High-Speed Railway Dynamic Logistics Alliance Based on the Dynamic Programming Model. *Journal of Advanced Transportation*, 2023(1), 6987845. https://doi.org/10.1155/2023/6987845

Yang, Z., Sun, Y., & Lee, P. T. W. (2020). Impact of the development of the China-Europe Railway Express: A case on the Chongqing International Logistics Center *Transportation Research Part A: Policy and Practice*, 136, 244-261. https://doi.org/10.1016/j.tra.2020.03.022https://doi.org/10.1016/j.tra.2020.03.022

Yegengil M, Arslan, H., & Sevinç, A. (2011). Örnek bir tedarik zincirinin sistem dinamikleri yaklaşımı ile modellenmesi. *International Journal of Engineering Research and Development*, vol. 3, no. 1, pp. 2-10.

Yu, Z., & Solis, D. (2019). Logistics Performance, Exports, and Growth: Evidence from Asian Countries *Research in Transportation Business & Management,* 31, 100378. https://doi.org/10.1016/j.rtbm.2019.100378

Zhang, Y., & Xiang, J. (2022). Has the Belt and Road Initiative promoted railway logistics efficiency?-An application of three-stage DEA *International Journal of Shipping and Transport Logistics*, 14(4), 348-370. https://doi.org/10.1504/IJSTL.2022.123713

Zhou, T., Wang, J., & Li, Y. (2022). Efficiency evaluation and influencing factors analysis of the logistics industry *Sustainability*, 14(15), 9427213. DOI: 10.3390/su14159427

Zhao, Y., Nasihatgozar, M., & Ming, F. (2024). The effect of nanoparticles on the economics study of railway logistics transport based on mathematical model *Advances in Nano Research*, 16(5), 521. DOI: 10.12989/anr.2024.16.5.521

Central Bank of the Republic of Turkiye (CBRT), https://www.tcmb.gov.tr/wps/wcm/connect/en/tcmb+en, 29.12.2024.

Councıl Of Supply Chaın Management Professıonals (CSCMP), Definitions of Supply Chain Management, https://cscmp.org/, 11.01.2025.

Ministry of Transport and Infrastructure General Directorate of Highways (MTIDDH). https://www.kgm.gov.tr/Sayfalar/KGM/SiteTr/Istatistikler/ButceOdenekHarcamaGelir.aspx, 29.12.2024.

Presidency of the Republic of Turkiye (PRT) (2024), Twelfth Development Plan (2024-2028), https://www.sbb.gov.tr/wp-content/uploads/2024/06/Twelfth-Development-Plan_2024-2028.pdf

Republic of Turkey Ministry of Transport and Infrastructure (RTMTI 1), https://denizcilikistatistikleri.uab.gov.tr/, 07.01.2025.

Republic of Turkiye-Ministry of Trade (TB) . Statistic. Retrieved from https://wwws.trades.govs.tr/statistics/statistic . 15. 02. 2025.

Republic of Turkey Ministry of Transport and Infrastructure (RTMTI 2), 2053 transport and logıstıcs master. Retrieved from https://www.uab.gov.tr/uploads/pages/bakanlik-yayinlari/2053-ulastirma-ve-lojistik-ana-plani-rev.pdf. 20.02.2025

Society for System Dynamics (2024). What is system dynamics? Retrieved from https://systemdynamics.org

Turkish Statistical Institute (TSI), 2024. https://data.tuik.gov.tr/Kategori/GetKategori?p=Transportation-and-Communication-112.

Wordbank (WB) (2025), https://databank.worldbank.org/indicator/NY.GDP.MKTP.CD/1ff4a498/Popular-Indicators, 04. 01.2025.