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An Optimization Approach to the Transportation Process Using Lean Logistics: A Case Study of Iran

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Highlights

- Identifying the key lean logistics factors and transportation barriers in Iran's petroleum distribution system.
- Integrating the Delphi method, structural equation modeling, the fuzzy analytic hierarchy process, and the VIKOR method to analyze the interrelationships among lean logistics components.
- Confirming the direct and indirect effects among lean logistics practices, evaluation criteria, and transportation barriers.
- Providing a comprehensive framework for optimizing transportation processes in petroleum distribution systems.

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Abstract

Optimizing transportation in organizational projects is critical, as identifying and evaluating transportation barriers represent key strategic decisions for managers and decision-makers. This study pursues three primary objectives: identifying the factors influencing lean logistics and transportation barriers, clarifying the interrelationships among the research criteria, and determining their relative importance and ranking in petroleum product distribution.

To achieve these objectives, a hybrid model was employed. First, the Delphi method was used to examine the interrelationships among the research criteria. In addition, fuzzy multi-criteria decision-making techniques, including the fuzzy Analytic Hierarchy Process, were applied to assign weights to the criteria. Subsequently, the VIKOR method was employed to prioritize the criteria.

The results confirm the existence of significant relationships among lean logistics, lean criteria, and transportation barriers. The findings further indicate that managerial barriers and lean managerial logistics represent the most critical obstacle and the most influential factor, respectively, in petroleum product distribution. These results provide practical guidance for managers seeking to enhance distribution performance and mitigate key transportation barriers.

Keywords: Delphi method, Fuzzy analytic hierarchy process, Optimization, Structural equation modeling, Transportation, VIKOR.

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1. Introduction

In Iran, a substantial volume of petroleum products is distributed annually through the national transportation network to meet the diverse demands of different regions (National Iranian Oil Refining and Distribution, 2023). These products are supplied from domestic refineries and imports and require coordinated and integrated transportation management. Effective management of this network is essential to address regional variations in demand. Given the country's resource constraints, optimizing the utilization of existing assets is critical for sustainable development. Similar to many developing countries, Iran faces significant challenges in resource allocation and supply; therefore, implementing effective solutions to address transportation inefficiencies is vital for meeting economic, social, and strategic objectives. An efficient transportation system facilitates economic activities and contributes substantially to social welfare and strategic operations at the national level (Kuzubov et al., 2024). Conversely, inefficiencies in the transportation network can cause disruptions and delays (Moshebah, Rodríguez-González and González, 2024), leading to considerable costs and constraining national development. Consequently, transportation system optimization has gained increasing attention in recent years and has become a central topic in sustainability discourse due to its broad economic and societal implications (Makarov and Abduryakhimova, 2024).

Although numerous studies have examined transportation and logistics optimization, many have focused primarily on discrete manufacturing systems or conventional distribution models. For example, Wang (2015) investigated lean logistics optimization in Chinese manufacturing, emphasizing discrete production systems such as customized manufacturing, whereas Pečený et al. (2020) analyzed the optimization of local transportation routes using relatively simple operational approaches. However, these studies did not adequately address the specific characteristics of continuous production systems, such as petroleum product distribution, nor did they fully consider the contextual challenges of developing economies such as Iran. These gaps highlight the need for a more comprehensive understanding of transportation network optimization in the petroleum distribution sector, particularly given Iran's economic dependence on the uninterrupted flow of petroleum products. Developing such an understanding requires identifying key influencing factors, analyzing complex causal relationships, and examining barriers that may hinder optimization efforts. These components are essential for improving strategic planning and enhancing transportation system performance for managers and decision-makers.

In response to these challenges, the present study adopts a comprehensive and integrative framework that combines structural equation modeling and fuzzy decision-making methods to identify key factors, analyze their interrelationships, and prioritize the criteria affecting logistics management, lean criteria, and optimization barriers in petroleum product distribution in Iran. Specifically, the study investigates the causal relationships among lean criteria, lean logistics, and transportation barriers and evaluates their combined impact on transportation performance. Structural equation modeling is employed to model these structural relationships, enabling a simultaneous and rigorous analysis. Subsequently, fuzzy multi-criteria decision-making methods, particularly the Analytic Hierarchy Process, are used to assign weights to the identified criteria and sub-criteria. Finally, the VIKOR method is applied to prioritize the most critical factors, with particular emphasis on barriers and influential elements within lean logistics.

Accordingly, the objective of this research is to identify and evaluate the significance of key lean indicators, lean logistics components, and critical barriers that impede the development of an efficient transportation system for petroleum product distribution. In addition, the study aims to clarify the interdependencies among these three dimensions using structural equation modeling. To accomplish these objectives, the study addresses the following research questions:

RQ1: What are the most critical lean logistics indicators and transportation barriers in the petroleum distribution sector?

RQ2: Among the identified factors across the three domains of lean indicators, lean logistics, and transportation barriers, which are the most influential in petroleum product distribution?

RQ3: Are there significant relationships between lean logistics indicators and lean criteria? What is the nature of the relationships between transportation barriers and lean logistics or lean criteria? When analyzed simultaneously, are all three dimensions significantly interrelated?

Addressing these questions provides a foundation for optimizing transportation systems based on lean logistics principles and offers a structured roadmap for researchers, practitioners, and strategic planners. The remainder of this paper is organized as follows: Section 2 reviews the theoretical background and identifies research gaps; Section 3 describes the research methodology and data analysis procedures; and Section 4 presents and discusses the findings and their practical implications.

2. Literature review

This section provides a concise summary of the literature review presented in this article.

2.1. A review of the lean concept in petroleum product distribution

The term “lean” originates from the concept of lean production introduced by Womack and colleagues. Over time, various definitions of lean have emerged, generally describing it as a systematic approach aimed at identifying and eliminating non-value-added activities through continuous improvement in order to enhance customer satisfaction. The lean philosophy typically emphasizes waste reduction, shorter design cycles, and flatter organizational structures, while simultaneously promoting employee empowerment, operational flexibility, productivity, and customer value. Although lean principles originated in manufacturing environments, they have been extended to and applied in other industries (Andrej E. Volkov, 2023; Subandi et al., 2023). However, implementing lean concepts beyond manufacturing presents significant challenges due to differences in operational structures and process characteristics (Sharma, Johari and Khatri, 2022).

The oil industry more closely resembles process industries that operate under continuous production systems (Dubié et al., 2023). This distinction increases the complexity of implementing lean tools and techniques, as many of these approaches were originally developed for discrete manufacturing systems characterized by batch production and intermittent operations. In contrast, continuous production systems depend on an uninterrupted flow of materials, which complicates the adoption of lean practices such as pull systems and certain forms of waste elimination. For example, Wang (2015) examined lean logistics in Chinese manufacturing firms, focusing on pull systems and waste minimization, and demonstrated the effectiveness of this approach in optimizing customized production processes. Nevertheless, due to structural and operational constraints, the application of such approaches in continuous systems, including petroleum product distribution, has received comparatively limited attention.

Although several successful applications of lean principles in process industries have been reported, their adoption remains lower than in discrete manufacturing. For instance, Al-Eqabi et al. (2023) investigated Petronas Oil Industries and explored how lean production and human resource flexibility contribute to cost reduction, with an emphasis on total quality management, automation, and continuous improvement. Similarly, Andry, Romadhon and Hamali (2022) demonstrated that leanness positively influences the social, economic, and environmental performance of the oil and gas supply chain and suggested that local content policies may further enhance these outcomes. In addition, Rachman and

Ratnayake (2019), through a systematic review, showed that lean principles have been applied effectively to improve operational performance in the petroleum industry, particularly in areas such as project management and supplier relationships. However, although their analysis addressed the upstream sector and discussed operational improvement, supplier relationships, and project management, it provided limited insight into the distribution of petroleum products.

Overall, the thematic review of the literature indicates that while lean principles have generated positive outcomes in various segments of the petroleum industry, especially in production and project management, their application to petroleum product distribution, particularly within continuous production systems, remains underexplored. Fundamental differences between discrete and continuous production systems, combined with the inherent complexities of the oil and gas supply chain, including reliance on fixed infrastructure and the requirement for uninterrupted flow, pose substantial challenges to the effective implementation of lean tools and techniques. These considerations reveal a significant research gap and underscore the need for a comprehensive and systematic investigation of the interrelationships among lean logistics, lean criteria, and transportation barriers in petroleum product distribution.

To address this gap, the present study employs a hybrid approach that integrates structural equation modeling and fuzzy multi-criteria decision-making methods to analyze these interrelationships within the context of petroleum product distribution in Iran. In doing so, the study advances the application of lean logistics principles in continuous production systems.

2.2. A review of barriers in the transportation system for petroleum product distribution

The distribution of petroleum products is subject to multiple barriers that significantly affect the efficiency and effectiveness of the overall system. These barriers, including environmental, logistical, and managerial challenges, vary across geographical and organizational contexts, making their accurate identification essential for performance improvement. This section reviews key studies in this area and identifies existing research gaps.

Satapathy (2024) identified major challenges in sustainable supply chain management for petroleum transportation, including carbon emissions, water pollution, and resource depletion. These environmental issues substantially affect the efficiency and safety of petroleum product transportation systems and underscore the need for more sustainable practices. In addition, Ufot et al. (2024) examined the impact of ethical distribution practices on petroleum supply efficiency and concluded that the implementation of robust ethical frameworks is essential for overcoming distribution barriers and improving overall supply chain performance. Similarly, Jianguo et al. (2023) highlighted distribution challenges in the petroleum sector, including price volatility, geopolitical tensions, environmental pressures, and the increasing demand for sustainable alternatives. They advocated the adoption of flexible and adaptive strategies to address these barriers effectively. Clement (2018) investigated distribution barriers in southwest Nigeria and identified pipeline vandalism and road accidents as primary obstacles to efficient petroleum distribution. The study suggested revitalizing rail transport as a safer and more reliable alternative.

Moradi and MirHassani (2015) addressed the scheduling of multiproduct pipelines for optimal petroleum transportation and integrated inventory management to satisfy daily customer demand, thereby proposing a solution to mitigate barriers within the distribution system and enhance transportation efficiency. Sun and Zhou (2017) proposed a knowledge-based, tree-structured framework to solve the Inventory Routing Problem in oil product distribution systems, with the objective of overcoming distribution barriers and optimizing routing and inventory decisions.

Furthermore, Obasanjo and Nwankwo (2014) analyzed the distribution challenges associated with petroleum products transported by road from PPMC Kaduna and identified mechanical failures, unloading delays, and supply shortages as major constraints. They recommended the adoption of new technologies and improved driver training to enhance distribution efficiency and observed a correlation between product volume and truck availability, indicating that logistical inefficiencies directly constrain distribution capacity. Finally, Contín, Correljé and Huerta (2001) examined the Spanish oil distribution system and found that fuel price ceiling regulations reduced competition by enabling established firms to coordinate pricing strategies, thereby creating significant barriers to market entry and competitive dynamics.

Despite the valuable contributions of these studies, the existing literature exhibits several limitations that justify the need for new analytical approaches. First, studies such as Satapathy (2024) and Moradi and MirHassani (2015) primarily focused on specific categories of barriers, environmental and logistical, respectively, without comprehensively examining the interrelationships among these factors, such as the potential link between environmental constraints and operational delays. This fragmented perspective limits a systemic understanding of the complexities inherent in petroleum product distribution. Second, the lean logistics framework, which emphasizes waste elimination and flow optimization, has rarely been applied in this context. For example, although Sun and Zhou (2017) and Obasanjo and Nwankwo (2014) addressed operational optimization, they did not explicitly consider systemic waste or inefficiencies resulting from misalignment and structural constraints across the entire distribution network. Third, the specific context of developing countries, particularly Iran, where economic stability is closely tied to the continuous flow of petroleum products, has not been thoroughly examined.

2.3. Research gap

Despite extensive research on lean principles and transportation optimization in petroleum product distribution, significant gaps remain in the academic literature. First, the simultaneous examination of the complex interrelationships among lean logistics, lean criteria, and transportation barriers has received limited attention. For example, Satapathy (2024) and Moradi and MirHassani (2015) focused on environmental and logistical barriers, respectively, yet they did not provide a comprehensive analysis of the mutual impacts of these factors. Second, although the lean logistics framework has been applied in certain areas of the oil industry, such as maintenance management (Rachman and Ratnayake, 2019), its application in petroleum product distribution—particularly in developing countries such as Iran, where resource constraints, economic dependence on oil, and transportation network complexities pose significant challenges—has not been thoroughly investigated. Third, existing studies have largely concentrated on specific aspects of transportation optimization. For instance, Sun and Zhou (2017) focused on route optimization, while Obasanjo and Nwankwo (2014) examined fleet management challenges.

However, structural differences in Iran, including infrastructural limitations, operational constraints, and economic reliance on oil, reduce the generalizability of these findings to the Iranian context. This situation underscores the need for a comprehensive approach that simultaneously addresses the complexities of Iran's transportation network, resource constraints, and economic implications. Addressing these gaps is essential for developing effective strategies to optimize petroleum product transportation networks, particularly in developing countries such as Iran. Accordingly, this study examines key lean logistics factors and analyzes their interrelations to identify barriers affecting transportation optimization. To achieve this, structural equation modeling (SEM) is employed to explore the multiple relationships among variables, while fuzzy multi-criteria decision-making methods

(Fuzzy AHP and VIKOR) are used to prioritize criteria under conditions of uncertainty. This framework not only addresses the research gap but also provides valuable insights for industry managers, policymakers, and strategic planners.

3. Research method and data analysis

This study adopts a descriptive survey design and aims to identify key lean logistics factors, lean criteria, and transportation barriers in the distribution of petroleum products in Iran. The statistical population comprises managers and experts from the National Iranian Oil Products Distribution Company (Fars region). To address the research questions and achieve the study objectives, a mixed-method approach was employed, including the Delphi method, structural equation modeling (SEM), and fuzzy multi-criteria decision-making techniques (Fuzzy AHP and VIKOR). These methods were selected for their suitability in addressing the complexity of the problem: the Delphi method facilitates expert consensus for factor identification in a data-scarce context, SEM enables the analysis of complex interrelationships among factors, Fuzzy AHP accounts for uncertainty in weighting criteria, and VIKOR provides a balanced approach for prioritizing barriers. Each stage of the methodology is described in detail below.

To identify the key lean logistics factors, lean criteria, and transportation barriers, a comprehensive literature review was first conducted, and initial criteria were extracted from previous studies. Using a content analysis approach, items with very low repetition frequency were excluded, and some actions were combined based on classifications found in the literature. To localize the criteria within the context of petroleum product distribution, the Delphi method was applied due to its ability to collect expert opinions and achieve consensus on complex issues (Moradi and Meybodi, 2024). The Delphi panel consisted of 14 managers and experts involved in petroleum product distribution and familiar with the subject, selected through non-random purposive judgmental sampling.

After determining the panel members, a list of influential criteria was compiled into a questionnaire, which was distributed and collected both in person and electronically to assess the importance of each criterion according to the panel members. Respondents were also invited to propose additional criteria in a comment section. Analysis of these open-ended responses revealed that the suggested criteria were conceptually aligned with the existing literature-identified criteria, and they were subsequently integrated. The questionnaires employed a Likert scale ranging from “very low impact” (1) to “very high impact” (5), with 3 considered neutral. This scale was divided into two ranges: disagreement (1–3) and agreement (3–5). Since the average responses for all questions fell within the agreement range, none of the actions were eliminated, indicating that the literature-identified criteria were considered relevant and impactful by the experts in petroleum product distribution. Table 1 presents the final criteria for the petroleum product distribution sector in Fars Province, Iran.

As shown in Table 1, the transportation barrier criteria are categorized into three main groups:

- **Logistics Management Barriers:** These encompass challenges related to fuel supply, financial resources, vehicle availability, and distribution processes.
- **Human Resource Barriers:** These include issues arising from government regulations, personnel shortages, and managerial inefficiencies.
- **Operational Barriers:** This category addresses problems associated with scheduling, operational procedures, and performance evaluation.

Table 1

Criteria extracted from the theoretical literature

Criteria	Sub-criteria	References
Lean Logistics	Lean management	LL1 (Julka, Subodh and Lamba, 2014); (Bing, Bloemhof-Ruwaard and Van der Vorst, 2014); (Antonowicz, 2014); (Chiarini and Chiarini, 2013); (CAO, ZHANG and LI, 2013); (Jirsák and Holman, 2012); (Melo and Wolsey, 2010)
	Lean service	LL2 (Julka, Subodh and Lamba, 2014); (Antonowicz, 2014); (Shafabakhsh, Hadjihoseinlou and Taghizadeh, 2014); (Bing, Bloemhof-Ruwaard and Van der Vorst, 2014); (CAO, ZHANG and LI, 2013); (Chiarini and Chiarini, 2013); (Jirsák and Holman, 2012)
	Lean distribution	LL3 (Bing, Bloemhof-Ruwaard and Van der Vorst, 2014); (Julka, Subodh and Lamba, 2014); (Shafabakhsh, Hadjihoseinlou and Taghizadeh, 2014); (Borndörfer et al., 2013); (Jirsák and Holman, 2012)
	Lean design	LL4 (Antonowicz, 2014); (Julka, Subodh and Lamba, 2014); (Jirsák and Holman, 2012); (Nikolaou, 2010)
	Lean supply	LL5 (Antonowicz, 2014); (CAO, ZHANG and LI, 2013)
	Lean employees	LL5 (Chiarini and Chiarini, 2013); (Julka, Subodh and Lamba, 2014); (Jirsák and Holman, 2012); (Moradi and Alirezaei, 2024)
	Lean resources	LL7 (Antonowicz, 2014); (Shafabakhsh, Hadjihoseinlou and Taghizadeh, 2014); (Nikolaou, 2010)
	Lean transportation	LL8 (Antonowicz, 2014); (Bing, Bloemhof-Ruwaard and Van der Vorst, 2014); (Julka, Subodh and Lamba, 2014); (Shafabakhsh, Hadjihoseinlou and Taghizadeh, 2014); (Chiarini and Chiarini, 2013); (Jirsák and Holman, 2012); (Nikolaou, 2010); (Borndörfer et al., 2013); (CAO, ZHANG and LI, 2013); (Melo and Wolsey, 2010)
Lean Criteria	Cost reduction	LC1 (Julka, Subodh and Lamba, 2014); (Shafabakhsh, Hadjihoseinlou and Taghizadeh, 2014); (CAO, ZHANG and LI, 2013); (Chiarini and Chiarini, 2013); (Jirsák and Holman, 2012); (Nikolaou, 2010); (Melo and Wolsey, 2010)
	Inventory reduction	LC2 (Antonowicz, 2014); (Jirsák and Holman, 2012); (Nikolaou, 2010)
	Eliminating waste	LC3 (Jirsák and Holman, 2012); (Nikolaou, 2010); (Chiarini and Chiarini, 2013)
	High quality	LC4 (Antonowicz, 2014); (Shafabakhsh, Hadjihoseinlou and Taghizadeh, 2014); (Chiarini and Chiarini, 2013); (Julka, Subodh and Lamba, 2014); (Jirsák and Holman, 2012); (CAO, ZHANG and LI, 2013); (Melo and Wolsey, 2010)
	High flexibility	LC5 (Jirsák and Holman, 2012); (Nikolaou, 2010)
	Speed of service delivery	LC6 (Antonowicz, 2014); (Bing, Bloemhof-Ruwaard and Van der Vorst, 2014); (Julka, Subodh and Lamba, 2014); (Shafabakhsh, Hadjihoseinlou and Taghizadeh, 2014); (CAO, ZHANG and LI, 2013); (Chiarini and Chiarini, 2013); (Jirsák and Holman, 2012); (Nikolaou, 2010)

Criteria	Sub-criteria	References
Transportation barriers	Fuel materials barriers LM1	(Tlili, Faiz and Krichen, 2014)
	Capital barriers LM2	(Jahihussain and Jayaraman, 2013)
	Vehicle's barriers LM3	(Tlili, Faiz and Krichen, 2014); (Kowalski et al., 2013)
	Distribution barriers LM4	(Tlili, Faiz and Krichen, 2014); (Gablinger, Yechiel and Shevah, 2014), (Karabuk, 2007)
	Government barriers R1	(Julka, Subodh and Lamba, 2014); (Gablinger, Yechiel and Shevah, 2014); (Chiarini and Chiarini, 2013)
	Staffing barriers R2	(Julka, Subodh and Lamba, 2014); (Antonowicz, 2014), (Chiarini and Chiarini, 2013)
	Management barriers R3	(Tlili, Faiz and Krichen, 2014); (Usman, 2014)
	Schedule barriers Tec Plm1	(Tlili, Faiz and Krichen, 2014); (Kang, Batta and Kwon, 2014); (Abounacer, Rekik and Renaud, 2014); (Kowalski et al., 2013), (Karabuk, 2007)
	Method barriers Tec Plm2	(Tlili, Faiz and Krichen, 2014)
	Assessment barriers Tec Plm3	(Cotrell et al., 2014); (Kang, Batta and Kwon, 2014)

In this study, the Delphi method was conducted in three rounds for the questionnaire on lean criteria and lean logistics, and in four rounds for the questionnaire on transportation barriers. The results of these iterative rounds are summarized in Table 2.

Table 2

Results of Kendall's coefficient and standard deviation

	Titles of questionnaires	Average standard deviation	Kendall's coefficient
Round 1	Questionnaire on Lean Criteria	0.535	0.63
	Questionnaire on Lean Logistics Criteria	0.581	0.64
	Questionnaire on Transportation Barriers	0.621	0.54
Round 2	Questionnaire on Lean Criteria	0.461	0.79
	Questionnaire on Lean Logistics Criteria	0.492	0.82
	Questionnaire on Transportation Barriers	0.585	0.65
Round 3	Questionnaire on Lean Criteria	0.421	0.83
	Questionnaire on Lean Logistics Criteria	0.438	0.87
	Questionnaire on Transportation Barriers	0.503	0.77
Round 4	Questionnaire on Lean Criteria	Reaching a Consensus	Reaching a Consensus
	Questionnaire on Lean Logistics Criteria	Reaching a Consensus	Reaching a Consensus
	Questionnaire on Transportation Barriers	0.459	0.81

Considering the Kendall coefficient values of 0.83, 0.87, and 0.81 in the third and fourth rounds, it can be concluded that the panel members exhibited a very strong consensus on the actions studied (Table 2). Following the identification of the criteria, three researcher-developed questionnaires were

designed: “Transportation Barriers Based on Lean Criteria,” “Lean Logistics Based on Lean Criteria,” and “Transportation Issues Based on Lean Logistics.” To ensure content validity, these questionnaires were reviewed by ten experts and faculty members, whose evaluations confirmed their validity. Subsequently, the questionnaires were distributed to the expert panel for completion and assessment.

After data collection, the Kaiser-Meyer-Olkin (KMO) index was examined to assess data adequacy, and Bartlett’s test was conducted to evaluate the presence of significant relationships among variables. Additionally, the normality of the research variables was assessed using the Shapiro-Wilk test. Once these assessments were confirmed, it was concluded that each criterion had been appropriately evaluated. Based on these results, the validity of the questionnaires (Section 3.1) and the research hypotheses could be tested using structural equation modeling (SEM). In the next phase, the criteria were ranked, with the final weights of the model’s criteria determined using the Fuzzy AHP technique and subsequently applied for prioritization using the VIKOR method.

3.1. Questions’ validity investigation

3.1.1. Validity of the questionnaire for key lean logistics factors

Figure 1 illustrates the measurement model (first-order confirmatory factor analysis) for the variable Key Factors of Lean Logistics in the standardized estimation mode. The factor loadings indicate the strength of the correlation between each observed variable (i.e., questionnaire item) and its corresponding latent construct (i.e., factor).

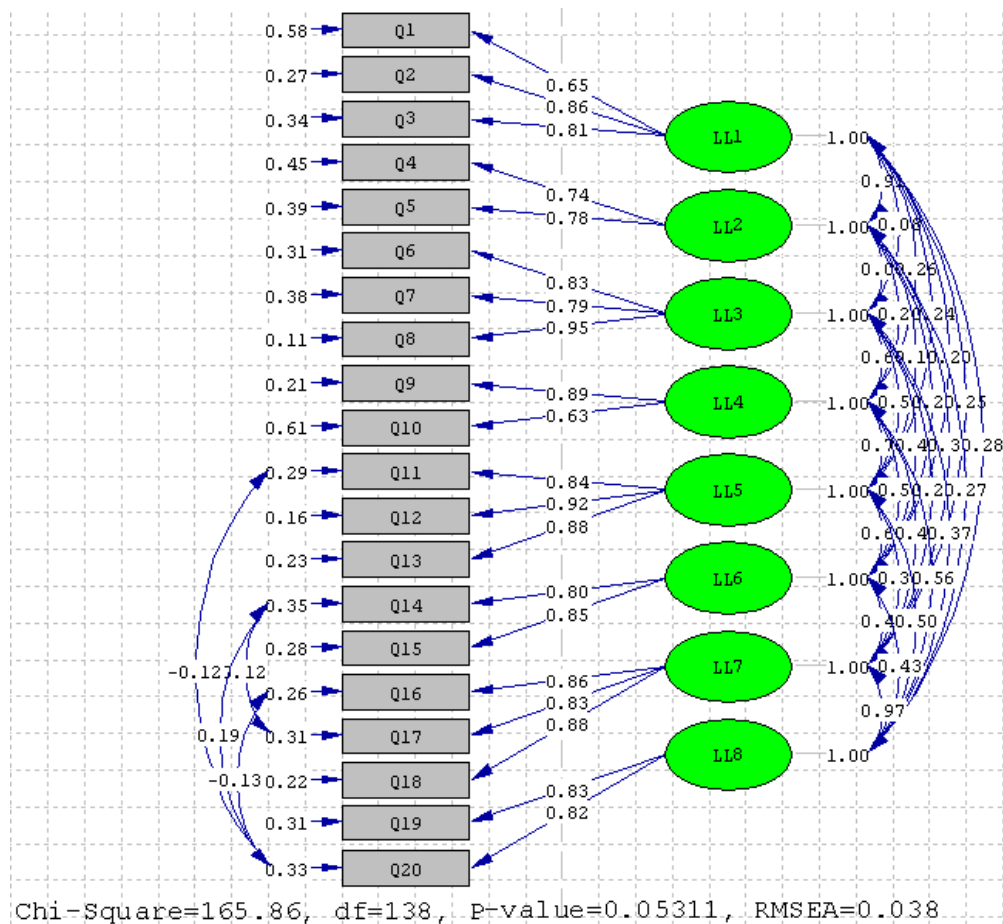


Figure 1

Measurement model of key lean logistics factors in standardized estimation mode

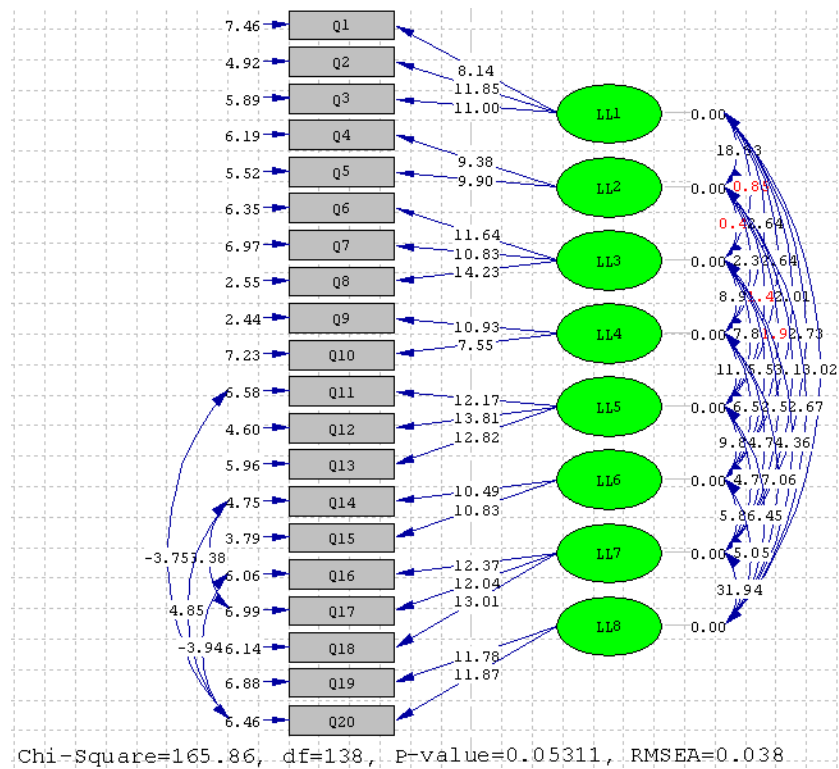
The average variance extracted (AVE), standardized factor loadings, their significance levels, and discriminant validity values for the measurement model of key lean logistics factors are summarized in Table 3.

Table 3

AVE and discriminant validity of the measurement model for lean logistics

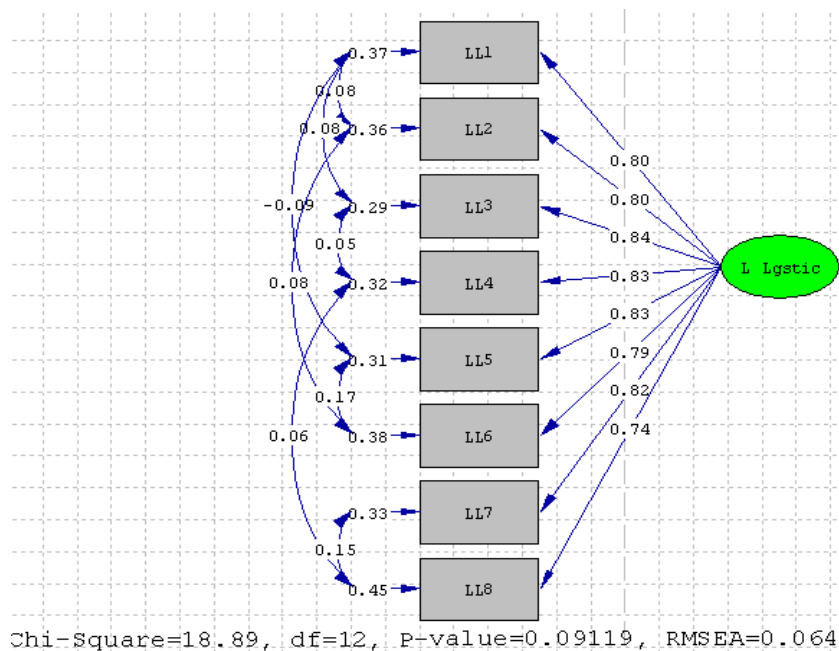
Variables	Question	Factor loading	Significance of factor loading	Extracted average variance (AVE)	Discriminant validity of variable
Lean Management	1	0.65	✓	0.606	✓
	2	0.86	✓		
	3	0.81	✓		
Lean Services	4	0.74	✓	0.578	✓
	5	0.78	✓		
	6	0.75	✓		
Lean Distribution	7	0.83	✓	0.739	✓
	8	0.79	✓		
	9	0.95	✓		
Lean Design	10	0.89	✓	0.595	✓
	11	0.74	✓		
	12	0.63	✓		
Lean Supply	13	0.84	✓	0.775	✓
	14	0.92	✓		
	15	0.88	✓		
Lean Workforce	16	0.80	✓	0.681	✓
	17	0.85	✓		
	18	0.81	✓		
Lean Resources	19	0.86	✓	0.734	✓
	20	0.83	✓		
	21	0.88	✓		
Lean Transportation	22	0.83	✓	0.681	✓
	23	0.85	✓		
	24	0.82	✓		

Given that the factor loadings exceed 0.5 and the average variance extracted (AVE) is also greater than 0.5, convergent validity is confirmed. Furthermore, the AVE for each criterion surpasses the squared correlations with the other criteria, confirming discriminant validity for all eight criteria. Figure 2 depicts the model in significance mode, affirming the significance of all coefficients. In addition, the T-values, all exceeding 1.96, indicate significant relationships at the 0.05 level.

**Figure 2**

Measurement model of key lean logistics factors in significance coefficient mode

It is important to note that twenty items were developed to assess the key lean logistics factors, which are grouped under eight indicators. The second-order confirmatory factor analysis of these key lean logistics factors, presented in standardized estimation mode, is illustrated in Figure 3.

**Figure 3**

Second-order factor analysis of key lean logistics factors in standard estimation mode

The average variance extracted (AVE), factor loadings and their significance, as well as the discriminant validity for the second-order confirmatory factor analysis of the key lean logistics factors, are presented in Table 4.

Table 4

AVE and second-order confirmatory factor analysis of key lean logistics factors

Factor	Variables	AVE	Significance of factor loading	Factor loading
Key lean logistics factor	Lean management	0.80	✓	0.651
	Lean service	0.80	✓	
	Lean distribution	0.84	✓	
	Lean design	0.83	✓	
	Lean supply	0.83	✓	
	Lean employees	0.79	✓	
	Lean resources	0.82	✓	
	Lean transportation	0.74	✓	

Given that the factor loadings exceed 0.5 and the average variance extracted (AVE) is also above 0.5, convergent validity is confirmed. The results of the second-order confirmatory factor analysis of the key lean logistics factors, shown in Figure 4, indicate that all factor loadings are statistically significant. Among the components of key lean logistics, distribution, design, and supply emerge as the most critical factors.

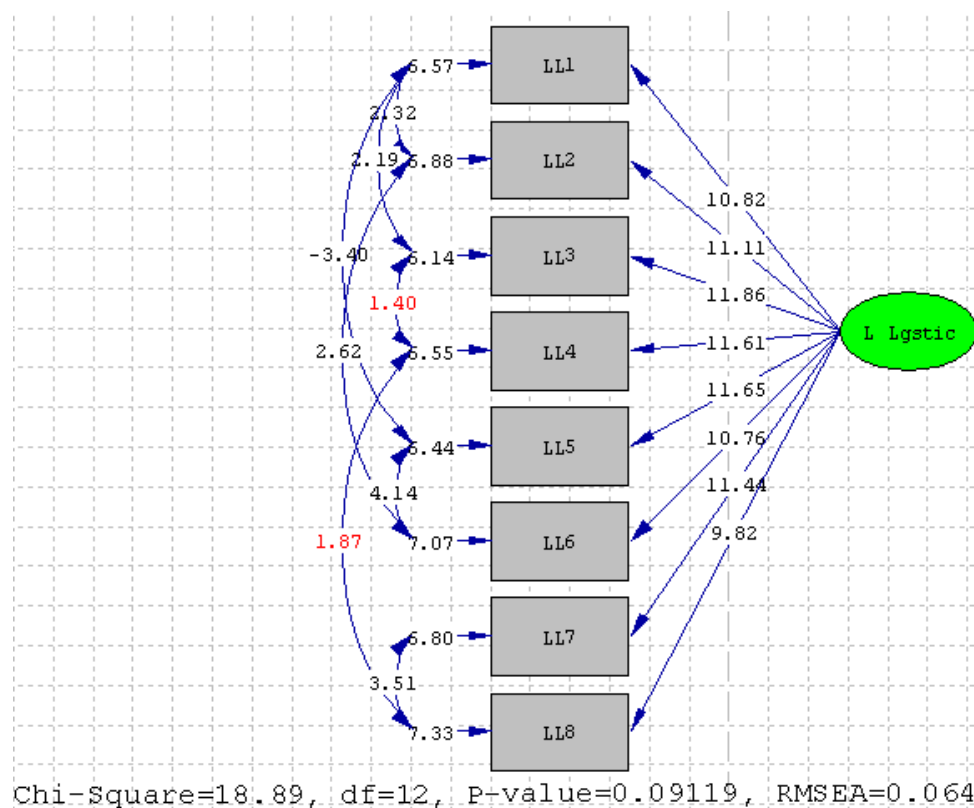


Figure 4

Second-order factor analysis of the key factors of lean logistics in standard estimation mode

The validity of all other questionnaires was similarly confirmed and, therefore, will not be discussed in detail here.

3.2. Questionnaire reliability

To evaluate the internal consistency of the questionnaires, Cronbach's alpha was calculated separately for each factor, and the results are presented in Table 5. The obtained Cronbach's alpha values for the different sections of the questionnaire indicate that the instrument demonstrates adequate reliability.

Table 5
Values of Cronbach's alpha for research variables

Variables	Number of questions	Variable's alpha
The key factors of lean logistics	20	0.833
Lean criteria	18	0.805
Logistics management	12	0.786
Technical problems	9	0.764
Resources	9	0.749

3.3. Hypothesis testing

The study criteria were successfully identified. To implement the SEM technique and evaluate the relationships among variables, it is first necessary to present the research hypotheses (Table 6).

Table 6
Research hypotheses

No	Hypothesis
1	The key lean logistics factors have a significant impact on the lean criteria.
2	The barriers of the transportation system have a significant impact on the lean criteria.
3	The barriers of the transportation system have a significant impact on the key lean logistics factors.

3.3.1. Testing the research hypotheses

In this section, the structural model and significance coefficients are examined for three key relationships:

1. The effect of key lean logistics factors on lean criteria.
2. The effect of transportation problems on lean criteria.
3. The effect of transportation problems on key lean logistics factors.

Additionally, the combined influence of these three dimensions and the final structural model are evaluated.

3.3.2. Testing primary research hypothesis 1

The first hypothesis of this study examines whether key lean logistics factors have a significant effect on lean criteria. Figures 5 and 6 illustrate the structural model for this hypothesis, presented in

standardized estimation mode and significance coefficient mode, respectively.

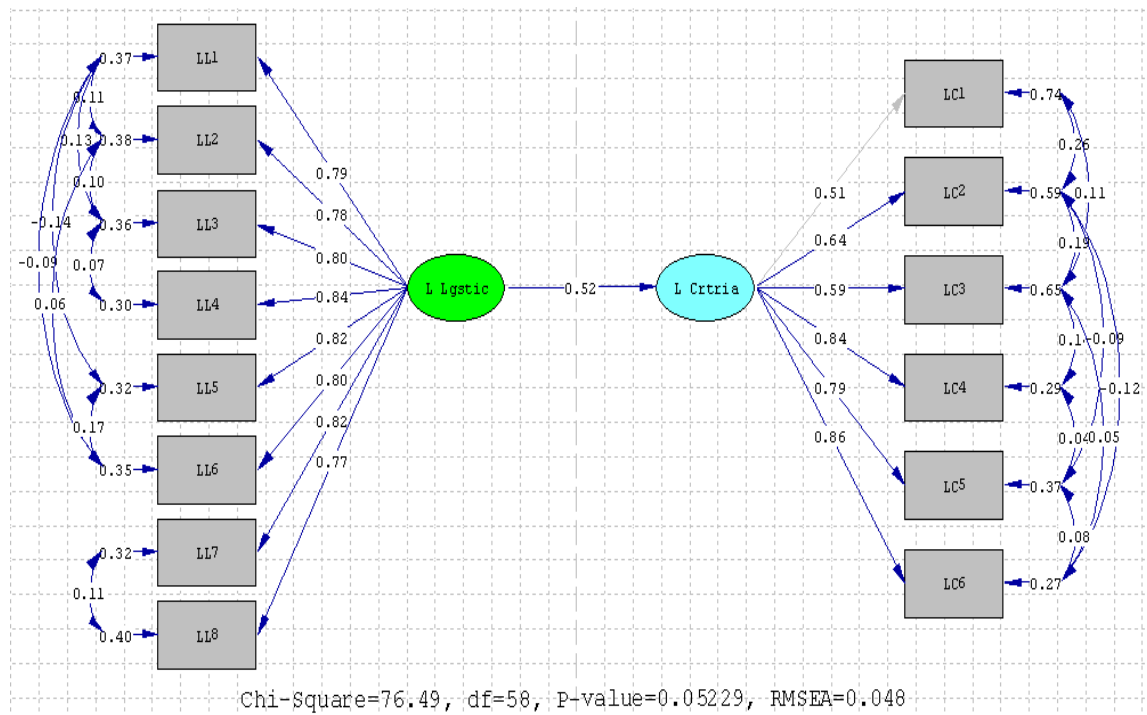


Figure 5

Structural model of hypothesis 1 in standard estimation mode

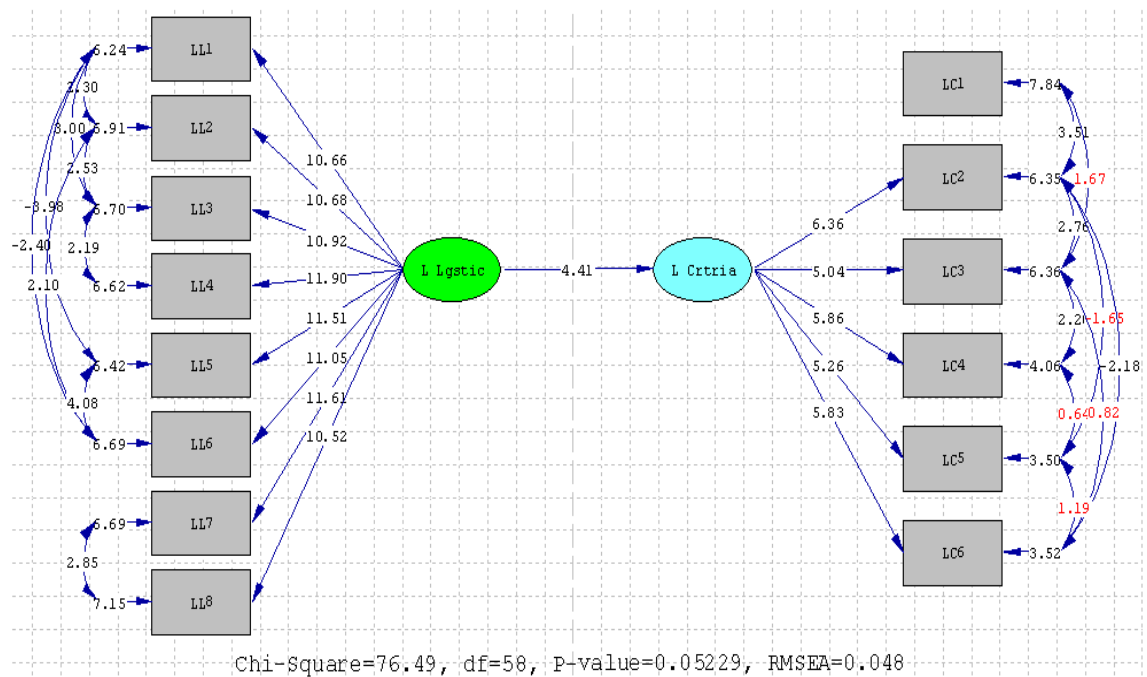


Figure 6

Structural model of hypothesis 1 in significance mode

The path coefficient between the key lean logistics factors and lean criteria is 0.52, indicating a positive relationship between these variables. In other words, a one-standard-unit increase in the key lean logistics factors (such as lean management improvement and lean design) results in a 0.52-standard-unit increase in lean criteria (such as cost reduction and waste elimination). The t-statistic for this path

coefficient is 4.41, which exceeds 1.96, indicating statistical significance at the 0.05 level. Therefore, the first hypothesis is confirmed. Table 7 summarizes the results of the first hypothesis test.

Table 7

Investigation of primary hypothesis 1

Research primary hypothesis No.1	Path coefficient	T	Result
The key factors of lean logistics have a significant effect on lean criteria.	0.52	4.41	H1 confirmed

The results support the third hypothesis at the 0.05 significance level. Table 8 presents the goodness-of-fit indices for the structural model corresponding to the first hypothesis.

Table 8

Goodness-of-fit indices for the structural model of hypothesis 1

Conceptual model fit indices	Calculated values	Acceptable values
χ^2/df	1.32	≤ 3
RMSEA	0.048	≤ 0.08
P-value	0.0523	$0.05 \leq$
GFI	0.92	$0.90 \leq$
AGFI	0.94	$0.90 \leq$
NFI	0.93	$0.90 \leq$
NNFI	0.94	$0.90 \leq$
CFI	0.91	$0.90 \leq$
IFI	0.96	$0.90 \leq$

The goodness-of-fit indices presented in Table 8 indicate a strong alignment between the conceptual model and the collected data. All indices fall within acceptable thresholds, confirming the adequacy of the model fit. These results suggest that the structural model for the first hypothesis is statistically robust.

3.3.3. Testing primary research hypothesis 2

The second primary hypothesis examines whether transportation barriers have a significant effect on lean criteria. To evaluate this hypothesis, structural equation modeling (SEM) was employed. Figures 7 and 8 illustrate the structural model for this hypothesis, showing the standardized estimates and significance coefficients, respectively.

The path coefficient between transportation barriers and lean criteria is -0.45 , indicating a moderate negative relationship between the two variables. In other words, a one-standard-deviation increase in transportation barriers corresponds to a 0.45-standard-deviation decrease in lean criteria. The t-statistic for this path coefficient is 4.89. Since this value exceeds the critical threshold of 1.96, the relationship is statistically significant at the 0.05 level. Table 9 summarizes the results of the hypothesis test for this relationship.

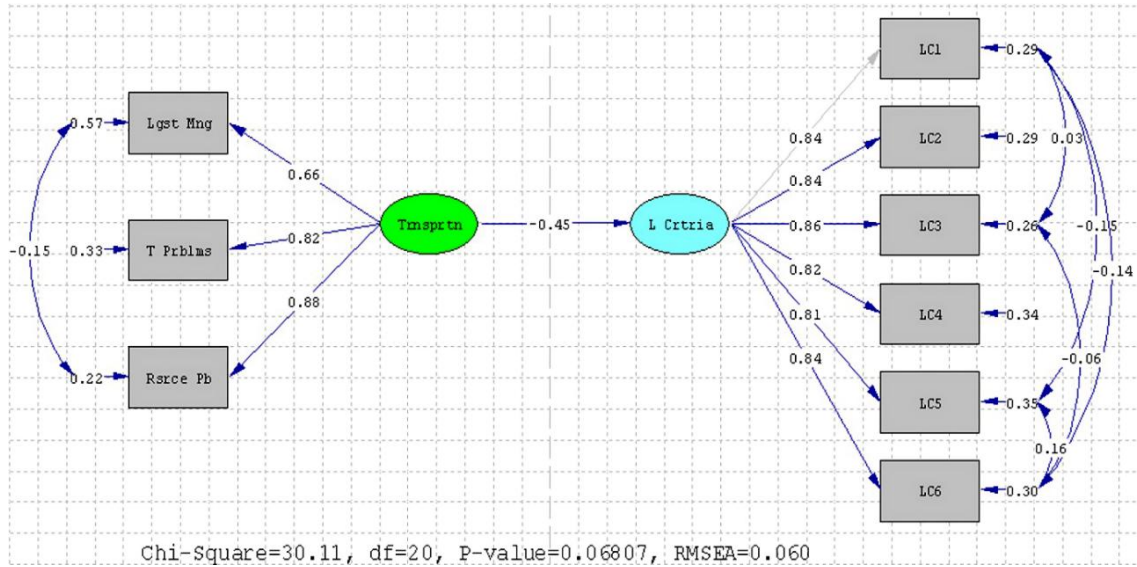


Figure 7

Structural model for primary research hypothesis 2 (standardized estimates)

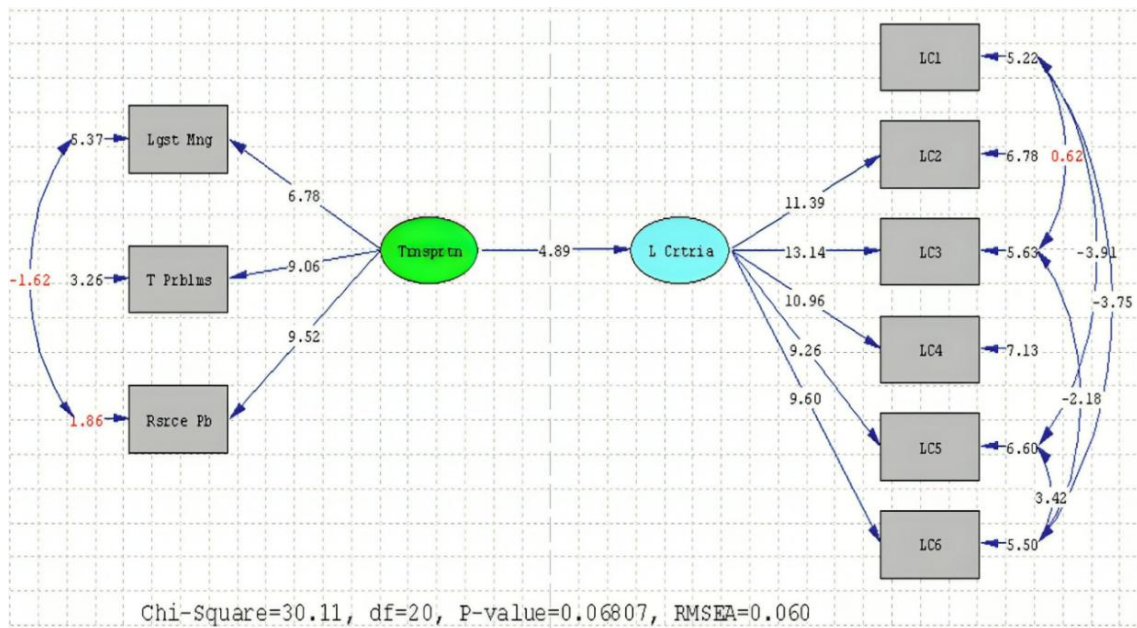


Figure 8

Structural model for primary research hypothesis 2 (significance coefficients)

Table 9

Investigation of primary research hypothesis 2

Research primary hypothesis No. 2	Path coefficient	T	Result
The transportation system problems have a significant effect on lean criteria.	-0.45	4.89	H1 confirmed

The results support the second hypothesis at the 0.05 significance level. Table 10 presents the goodness-of-fit indices for the structural model corresponding to the second hypothesis.

Table 10

Goodness-of-fit indices for the structural model of hypothesis 2

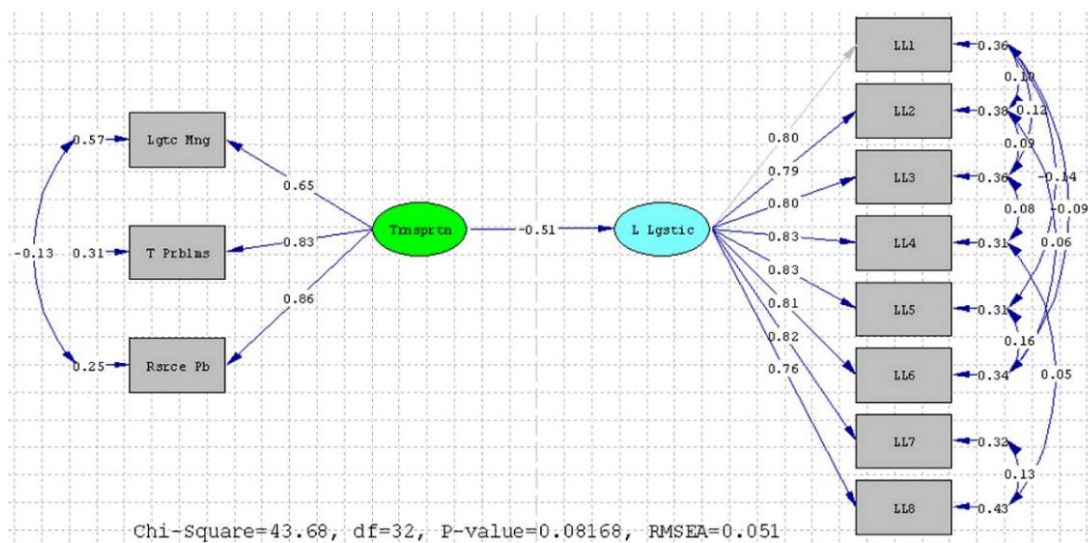
Conceptual model fit indices	Calculated values	Acceptable values
χ^2/df	1.51	≤ 3
RMSEA	0.045	≤ 0.08
P-value	0.0534	$0.05 \leq$
GFI	0.95	$0.90 \leq$
AGFI	0.96	$0.90 \leq$
NFI	0.91	$0.90 \leq$
NNFI	0.93	$0.90 \leq$
CFI	0.92	$0.90 \leq$
IFI	0.93	$0.90 \leq$

The goodness-of-fit indices in Table 10 indicate a strong alignment between the conceptual model and the collected data. These results demonstrate that the structural model for the second hypothesis is statistically robust.

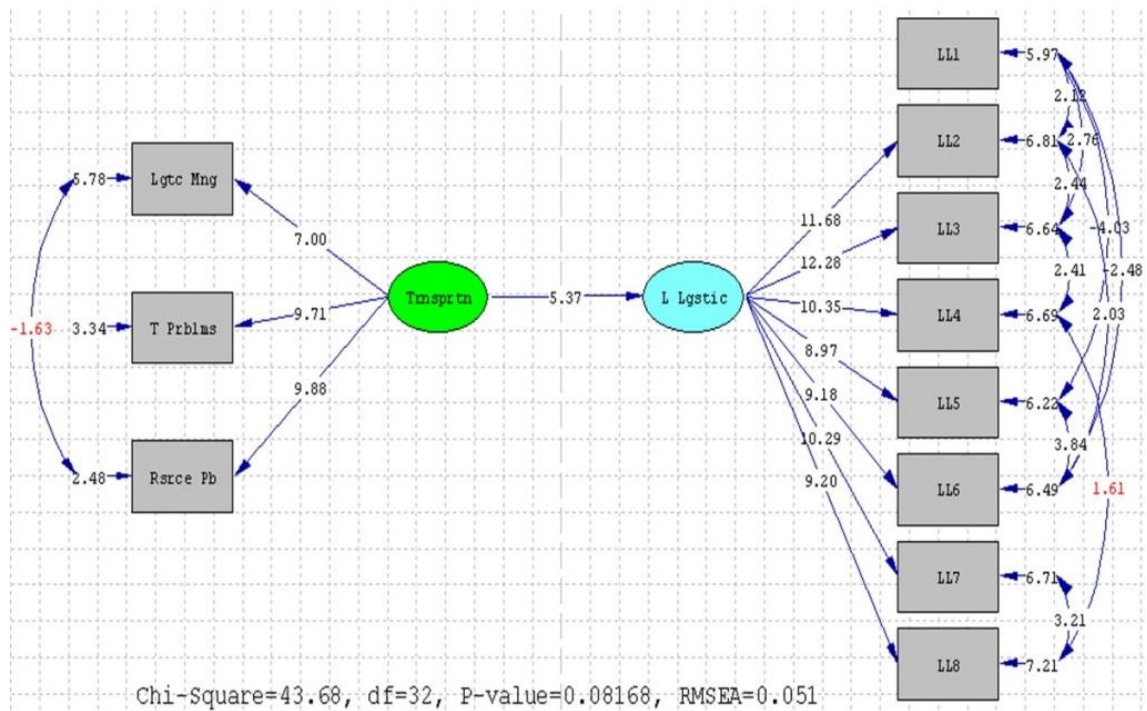
3.3.4. Testing primary research hypothesis 3

The third hypothesis of this study examines whether transportation barriers have a significant effect on the key factors of lean logistics. To evaluate this hypothesis, structural equation modeling (SEM) was applied. Figures 9 and 10 illustrate the structural model for this hypothesis, showing the standardized estimates and significance coefficients, respectively.

The path coefficient between transportation barriers and the key factors of lean logistics is -0.51 , indicating a moderate negative relationship between these variables. In other words, a one-standard-deviation increase in transportation barriers corresponds to a 0.51-standard-deviation decrease in the key factors of lean logistics. The t-statistic for this path coefficient is 5.37, which exceeds the critical value of 1.96, indicating that the relationship is statistically significant at the 0.05 level. Table 11 summarizes the results of the hypothesis test for this relationship.

**Figure 9**

Structural model for primary hypothesis 3 (standardized estimates)

**Figure 10**

Structural model for primary hypothesis 3 (significance coefficients)

Table 11

Summary of results for primary research hypothesis 3

Research primary hypothesis No. 3	Path coefficient	T	Result
The transportation system problems have a significant effect on the key factors of lean logistics.	-0.51	5.37	H1 confirmed

Based on the results, the third hypothesis is supported at the 0.05 significance level. Table 12 presents the goodness-of-fit indices for the structural model corresponding to this hypothesis.

Table 12

Goodness-of-fit indices for the structural model of hypothesis 3

Conceptual model fit indices	Calculated values	Acceptable values
χ^2/df	1.37	≤ 3
RMSEA	0.041	≤ 0.08
P-value	0.082	$0.05 \leq$
GFI	0.97	$0.90 \leq$
AGFI	0.97	$0.90 \leq$
NFI	0.96	$0.90 \leq$
NNFI	0.98	$0.90 \leq$
CFI	0.95	$0.90 \leq$
IFI	0.95	$0.90 \leq$

The goodness-of-fit indices presented in Table 12 indicate a strong alignment between the conceptual model and the collected data. All indices fall within the acceptable range, confirming the model's

adequate fit. These results demonstrate that the structural model for the third hypothesis is statistically robust.

3.3.5. Simultaneous analysis of the relationships between transportation barriers, lean criteria, and lean logistics

This section investigates the simultaneous effects of transportation barriers on both lean criteria and lean logistics. Structural equation modeling (SEM) was employed to analyze these relationships. Figures 11 and 12 present the structural model, showing the standardized estimates and significance coefficients, respectively.

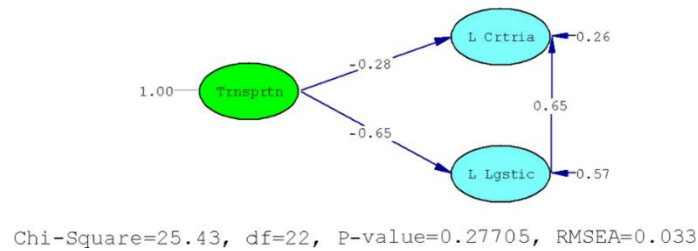


Figure 11

Structural model of the research framework (standardized estimates)

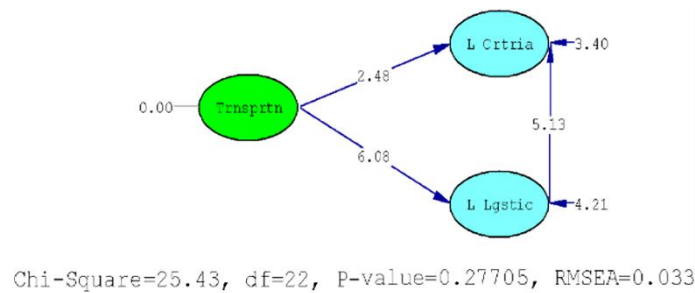


Figure 12

Structural model of the research framework (significance coefficients)

According to Table 13, the path coefficient between transportation barriers and lean logistics is -0.65 , indicating a strong negative relationship between these variables. In other words, a one-standard-deviation increase in transportation barriers leads to a 0.65-standard-deviation decrease in lean logistics. The t-statistic for this path coefficient is 6.08, which exceeds the critical value of 1.96, indicating statistical significance at the 0.05 level.

The path coefficient between transportation barriers and lean criteria is -0.28 , indicating a weak negative relationship. Specifically, a one-standard-deviation increase in transportation barriers results in a 0.28-standard-deviation decrease in lean criteria. The t-statistic for this coefficient is 2.48, which is also statistically significant at the 0.05 level.

The path coefficient between lean criteria and lean logistics is 0.65, reflecting a strong positive relationship between these variables. In other words, a one-standard-deviation increase in lean criteria corresponds to a 0.65-standard-deviation increase in lean logistics. The t-statistic for this path is 5.13, indicating statistical significance at the 0.05 level.

Table 13

Summary of simultaneous relationships between transportation barriers, lean criteria, and lean logistics

Research hypotheses	Test results	Statistics	Path coefficient		
			Total	Indirect	Direct
The transportation system problems have a significant impact on the key factors of lean logistics.	Approval H ₁	6.08	-0.65	--	-0.65
The transportation system problems have a significant impact on lean criteria.	Approval H ₁	6.64	-0.70	-0.42	-0.28
The key factors of lean logistics have a significant impact on lean criteria.	Approval H ₁	5.13	0.65	--	0.65

Table 14 presents the goodness-of-fit indices for the structural model discussed in this section.

Table 14

Goodness-of-fit indices for the simultaneous model of transportation barriers, lean criteria, and lean logistics

Conceptual model fit indices	Calculated values	Acceptable values
χ^2/df	1.16	≤ 3
RMSEA	0.033	≤ 0.08
P-value	0.277	$0.05 \leq$
GFI	0.96	$0.90 \leq$
AGFI	0.92	$0.90 \leq$
NFI	0.96	$0.90 \leq$
NNFI	0.97	$0.90 \leq$
CFI	0.95	$0.90 \leq$
IFI	0.95	$0.90 \leq$

The goodness-of-fit indices presented in Table 14 demonstrate a satisfactory alignment between the conceptual model and the collected data. All indices fall within acceptable ranges, confirming the adequacy of the model fit. These results indicate that the structural model in this section is statistically robust.

3.4. Prioritization of criteria using fuzzy multi-criteria decision-making

In the previous stage, the relationships and effects of key lean logistics factors on lean criteria, as well as the influence of transportation system barriers on both lean criteria and key lean logistics factors, were examined using SEM. In the current stage, fuzzy multi-criteria decision-making (MCDM) techniques are employed to prioritize the sub-criteria. This approach involves two main steps: first, fuzzy AHP is used to determine the weights of the sub-criteria; second, the VIKOR method is applied to rank the alternatives. This methodology was chosen for its ability to manage uncertainty and complexity in decision-making, making it particularly suitable for the present study.

3.4.1. Prioritizing criteria using the fuzzy AHP technique

Following the development of the causal relationship model, the relationships between the criteria and sub-criteria were determined using a pairwise comparison matrix. To this end, a questionnaire based on

Saaty's nine-point scale was designed and distributed to experts, and the opinions of ten experts were collected during this phase. The primary criteria in this study are transportation barriers, lean criteria, and lean logistics criteria, each of which consists of several sub-criteria. The final weights of the sub-criteria were calculated using Super Decisions software, selected for its capability to manage the complexity of multi-criteria decision-making. The results, along with the corresponding weights, are presented in the following three subsections.

a. Prioritization of transportation system barriers based on lean logistics

In this stage, the ten transportation system barriers are prioritized according to the eight lean logistics factors. The final weights of the lean logistics criteria were determined using fuzzy AHP, as presented in Table 15. These weights were then applied using the VIKOR method, with the results shown in Table 16.

Table 15

Ranking of transportation system barriers based on lean logistics using the fuzzy AHP technique

Criteria	Sub-criteria	Final weight	Ranked
Lean logistics criteria	Lean management	0.208	1
	Lean service	0.105	5
	Lean distribution	0.072	7
	Lean design	0.137	4
	Lean supply	0.090	6
	Lean employees	0.155	3
	Lean resources	0.178	2
	Lean transportation	0.055	8

b. Prioritization of transportation system barriers based on lean metrics

In this stage, transportation system barriers are prioritized based on lean metrics, and the lean logistics criteria are also ranked according to lean metrics. First, the final weights of the key lean metrics are calculated using the fuzzy AHP technique (see Table 15). These weights are then applied in the VIKOR method to prioritize both the influential factors and the existing barriers in the transportation system. The results are presented in Table 17.

Table 16

Prioritization of transportation system barriers based on lean metrics using the fuzzy AHP technique

Criteria	Sub-criteria	Final weight	Ranked
Lean factors	Cost reduction	0.297	1
	Inventory reduction	0.115	5
	Eliminating waste	0.118	4
	High quality	0.162	3
	High flexibility	0.195	2
	Speed of service delivery	0.113	6

3.4.2. Ranking sub-criteria using the VIKOR technique

In the previous step, the criteria and sub-criteria were weighted and ranked using the fuzzy AHP method. In this step, the final weights obtained from the fuzzy AHP model are applied to prioritize the criteria using the VIKOR method. The results for prioritizing transportation system barriers based on both lean metrics and lean logistics factors are summarized in Table 16.

Table 17

Ranking transportation system barriers based on lean metrics and lean logistics factors using the VIKOR technique

	Barriers of the transportation system based on lean logistics						Barriers of the transportation system based on lean factors					
	Q		R		S		Q		R		S	
	Quant	Rank	Quant	Rank	Quant	Rank	Quant	Rank	Quant	Rank	Quant	Rank
Assessment barriers	0.408	5	0.167	7	0.607	8	0.2664	5	0.1803	7	0.3450	2
Method barriers	0.266	3	0.184	9	0.608	9	0.2219	3	0.1299	3	0.4472	4
Staffing barriers	0.26	2	0.177	8	0.638	10	0.1518	2	0.1015	1	0.4504	5
Capital barriers	0.658	7	0.155	3	0.54	6	0.4239	7	0.1620	6	0.5924	8
Schedule barriers	0.388	4	0.208	10	0.46	3	0.2482	4	0.1591	5	0.3887	3
Vehicle barriers	0.524	6	0.158	5	0.591	7	0.3502	6	0.1352	4	0.5860	7
Distribution barriers	0.822	9	0.152	2	0.478	4	0.7369	9	0.2970	10	0.5533	6
Management barriers	0.092	1	0.158	5	0.409	1	0.0347	1	0.1151	2	0.2667	1
Fuel barriers	0.967	10	0.148	1	0.424	2	0.9084	10	0.2612	9	0.8717	10
Government barriers	0.750	8	0.155	3	0.498	5	0.5280	8	0.1838	8	0.6509	9

Additionally, the prioritization of lean logistics criteria based on lean metrics is presented in Table 18.

Table 18

Ranking of lean logistics criteria based on lean metrics using the VIKOR technique

	Lean logistics criteria based on lean metrics					
	Q		R		S	
	Quant	Rank	Quant	Rank	Quant	Rank
Lean management	0.0354	1	0.1150	3	0.2718	1
Lean service	0.7459	7	0.1975	7	0.7351	8
Lean distribution	0.3457	6	0.1950	6	0.3702	2
Lean design	0.2931	4	0.1620	5	0.3995	3
Lean supply	0.3031	5	0.1011	1	0.5527	7
Lean employees	0.2440	2	0.1130	2	0.4698	4
Lean resources	0.2776	3	0.1252	4	0.4721	5
Lean transportation	0.7597	8	0.2970	8	0.5125	6

Table 19 presents the results of the prioritization of transportation system barriers and lean logistics factors. The results indicate that managerial barriers are ranked highest among the transportation system barriers, while lean management ranks highest among the eight lean logistics factors.

Table 19
Ranking of transportation barriers and lean logistics factors

Transportation barriers	Rank by VIKOR	Logistics factors	Rank by VIKOR
Assessment barriers	5	Lean management	1
Method barriers	3	Lean service	7
Staffing barriers	2	Lean distribution	6
Capital barriers	7	Lean design	4
Schedule barriers	4	Lean supply	5
Vehicle's barriers	6	Lean employees	2
Distribution barriers	9	Lean resources	3
Management barriers	1	Lean transportation	8
Fuel barriers	10		
Government barriers	8		

The prioritization results in Table 19, derived from the VIKOR analysis of transportation barriers based on lean logistics factors (as detailed in Table 16), indicate that management barriers (R3) rank first among transportation system barriers, with the lowest Q value of 0.0347. This finding highlights the critical role of management barriers in hindering the optimization of Iran's petroleum distribution system. Management barriers—including inefficiencies in decision-making, lack of strategic planning, and poor coordination among stakeholders—are particularly significant in the Iranian context due to systemic challenges. These issues often exacerbate operational inefficiencies, such as staffing barriers (R2), which rank second among transportation barriers with a Q value of 0.1518. Inadequate workforce management can result in delays, increased operational costs, and reduced overall system performance.

Furthermore, the prominence of management barriers aligns with the top ranking of lean management (LL1) among lean logistics factors, with a Q value of 0.092 (as shown in Table 16), and cost reduction (C1) as the highest-ranked lean criterion, with a final weight of 0.297 according to the fuzzy AHP results. This alignment underscores the importance of effective management practices in achieving core lean objectives, such as cost minimization and waste reduction, particularly in complex systems like petroleum distribution. These insights suggest that targeted interventions to address management barriers—such as enhanced training, improved coordination, and strategic planning—could substantially improve the efficiency of Iran's petroleum transportation system. This point is further elaborated in Section 5.

4. Discussion and conclusions

This study aimed to identify the key factors of lean logistics, lean criteria, and transportation barriers in the distribution of petroleum products in Iran. A comprehensive methodological approach, combining the Delphi method, SEM, and fuzzy multi-criteria decision-making techniques (Fuzzy AHP and VIKOR), was employed to examine the interrelationships among these factors and their prioritization. The findings provide valuable insights for managers and policymakers in the petroleum distribution sector, particularly in developing countries such as Iran.

Confirmatory factor analysis revealed that lean distribution, lean design, and lean supply were the most significant key factors of lean logistics (see Table 4). However, the prioritization results obtained using Fuzzy AHP and VIKOR indicated that lean management and lean personnel were the most critical sub-criteria within lean logistics (see Table 19). Concurrently, cost reduction and waste elimination emerged as the most important lean criteria, while managerial and personnel barriers were identified as the primary obstacles in the transportation system (see Tables 15 and 19). These findings underscore the central role of human capital and effective management in enhancing transportation systems, especially in contexts characterized by economic sanctions, outdated infrastructure, and limited resources, such as Iran.

This study contributes to the broader body of knowledge in lean logistics and transportation management and addresses a notable gap in the literature by developing a localized and integrated framework tailored to developing countries. Whereas many previous studies have focused predominantly on developed economies, this research offers specific insights into emerging markets. The results highlight that lean management and lean personnel are crucial for the successful implementation of lean logistics principles in developing nations, emphasizing the need for targeted investments in managerial capabilities and workforce development.

Furthermore, the identification of managerial and personnel barriers as the most significant obstacles in transportation optimization reinforces the importance of adopting efficient management practices and strengthening human resource capacities. These findings suggest that any strategy aimed at improving transportation performance in developing countries should prioritize human capital development and effective leadership. Such a focus will facilitate continuous improvement in reducing costs and eliminating waste, two core lean objectives identified as most significant in this study.

In practical terms, these insights enable organizations to identify the most critical factors and barriers in optimizing transportation systems. Consequently, companies can design specific strategies to reduce costs, enhance operational efficiency, and minimize risks. For instance, by investing in improved management systems and targeted staff training programs, the National Iranian Oil Products Distribution Company can significantly enhance the performance of its transportation operations and reduce associated costs.

Given that this research was conducted in the context of Iran, its findings can serve as a foundation for formulating localized policies and regional strategies to boost productivity within the petroleum distribution sector. Moreover, the analytical and strategic insights derived from this study provide valuable guidance for stakeholders and decision-makers across economic and industrial sectors, supporting more effective planning, operational improvements, and evidence-based policymaking.

The research questions are addressed in detail in the following sections, followed by an analysis of key findings. The theoretical and practical implications, limitations, and recommendations for future research are also discussed. This study was guided by three primary research questions:

RQ1: What are the most critical lean logistics indicators and transportation barriers in the petroleum distribution sector?

To address this question, a comprehensive literature review was conducted to identify an initial set of relevant factors. Items with low frequency were subsequently removed through content analysis, and some variables were merged in accordance with prior classifications found in the literature. To localize and contextualize these factors for Iran's petroleum distribution sector, the Delphi method was employed. A panel of 14 experts and managers from the National Iranian Oil Products Distribution Company (Fars region), selected via purposive sampling, participated in the Delphi process. A

structured questionnaire based on a five-point Likert scale was administered over three rounds for lean criteria and lean logistics, and four rounds for transportation barriers. The level of expert consensus was high, with Kendall's agreement coefficients of 0.85 for lean criteria and lean logistics, and 0.81 for transportation barriers (Table 2), indicating strong alignment among experts. As a result, eight key lean logistics factors, six lean criteria, and ten transportation barriers were finalized (Table 1). This localization effort, a key innovation of the study, allowed for the identification of factors uniquely aligned with the operational and contextual challenges of petroleum product distribution in Iran.

RQ2: Among the identified factors across the three domains (lean indicators, lean logistics, and transportation barriers), which are the most influential in petroleum product distribution?

Following the identification of key factors, a hypothetical model was developed. The causal relationships among the variables were analyzed and ranked using a combination of SEM (LISREL), Fuzzy AHP, and the VIKOR method. The results indicated that among the transportation barriers, managerial barriers (ranked 1st) and personnel barriers (ranked 2nd) had the most substantial negative impact on transportation performance (Table 19). This underscores the critical role of human resources and decision-making structures in shaping organizational outcomes. These findings align with Abdi, Djaber, and Zennadi (2024), who similarly emphasized managerial and personnel challenges as key impediments in petroleum product transportation. This study further demonstrates that in developing countries such as Iran, where resource constraints and structural limitations are more acute, these barriers exert a stronger negative influence, necessitating targeted organizational strategies.

Among the sub-criteria of lean logistics, lean management (ranked 1st) and lean personnel (ranked 2nd) emerged as the most influential elements (Table 19), highlighting the importance of capable leadership and a skilled workforce for successful implementation of lean principles, consistent with Pawlak and Gibus (2024). However, the application of these factors in Iran's petroleum distribution sector may be constrained by local challenges, including economic sanctions, bureaucratic inefficiencies, and limited infrastructure. Regarding lean criteria, cost reduction and waste elimination were ranked first and second, respectively (Table 15), aligning with the core principles of the lean concept (Womack, Jones, and Roos, 2007), which emphasize cost reduction and waste elimination. In petroleum product transportation systems, financial and operational constraints have led organizations to focus more strongly on economic optimization and cost management. These results highlight the importance of strengthening managerial, human resource, and organizational capabilities to facilitate lean implementation and achieve key objectives such as cost reduction and waste elimination.

RQ3: Are there significant relationships between lean logistics indicators and lean criteria? What is the nature of the relationship between transportation barriers and lean logistics or lean criteria? When considered simultaneously, are all three dimensions significantly interrelated?

To address this question, a structural equation model (SEM) was developed to examine the interrelationships among the three domains. The findings are summarized as follows:

Hypothesis 1: The results indicate that key lean logistics factors significantly influence lean criteria. In the standardized estimation, the path coefficient was 0.52, demonstrating a positive effect of key lean logistics factors on lean criteria. Moreover, the significance level, with a t-statistic of 4.41, confirmed the existence of a statistically meaningful relationship between lean logistics and lean criteria (Figures 6 and 7). Therefore, the first hypothesis is supported. This finding aligns with Chistnikova, Ermachenko, and Gunter (2021), who showed that lean logistics can enhance lean criteria such as cost reduction and waste elimination. By focusing on Iran and continuous production systems, including petroleum product distribution, this study further demonstrates that the relationship is particularly significant given operational complexities and country-specific challenges, including economic

sanctions and infrastructural constraints. These results underscore the importance of strengthening key lean logistics factors to effectively achieve lean objectives in such contexts.

Hypothesis 2: The analysis showed that transportation system barriers significantly affect lean criteria. In the standardized estimation, the path coefficient was -0.45 , indicating a negative impact of transportation system barriers, including managerial and personnel obstacles, on lean criteria such as cost reduction and waste elimination. Furthermore, the significance coefficient, with a t-statistic of 4.89, confirmed the presence of a statistically meaningful relationship. Thus, the second hypothesis is supported. This finding is consistent with Preetpal and Mahipal (2023), who demonstrated that managerial barriers (e.g., inefficient management) and personnel barriers (e.g., lack of employee skills) can impede the achievement of lean objectives. These results highlight the importance of addressing such barriers to enhance efficiency in petroleum product distribution systems, particularly in contexts such as Iran, where infrastructural and economic challenges persist.

Hypothesis 3: The results indicate that transportation system barriers significantly impact key lean logistics factors. In the standardized estimation, the path coefficient was -0.51 , illustrating a negative effect of transportation system barriers on lean logistics. Additionally, the significance level, with a t-statistic of 5.37, confirms the presence of a statistically meaningful relationship between transportation system barriers and lean logistics. Therefore, the third hypothesis is supported. This finding emphasizes the need to identify and mitigate transportation system barriers, as their reduction can enhance the effective implementation of lean logistics within petroleum product distribution systems.

A simultaneous examination of the relationships among transportation system barriers, lean logistics, and lean criteria revealed a significant degree of interconnection. Specifically, transportation system barriers were found to affect lean criteria both directly (path coefficient: -0.28) and indirectly through lean logistics (indirect path coefficient: -0.42) (Figures 12 and 13; Table 13). The indirect effect was calculated by multiplying the path coefficients of transportation system barriers and key lean logistics factors. The total effect of transportation system barriers on lean criteria was -0.70 . This simultaneous analysis, a novel contribution of this study, highlights the complexity of the interrelationships among these factors and underscores the necessity of an integrated approach to transportation system optimization. Notably, the findings suggest that addressing transportation system barriers not only directly improves lean criteria but also indirectly enhances them by strengthening key lean logistics factors. This insight can assist managers in developing comprehensive strategies to improve efficiency within petroleum product distribution systems.

For structural model validation across all three hypotheses, model fit indices such as RMSEA and p-values (reported in Tables 8, 10, 12, and 14) were evaluated using structural equation modeling. The results confirmed that the research models exhibit good fit, meeting accepted thresholds for these indices.

This study provides several managerial implications for optimizing transportation systems and enhancing efficiency in petroleum product distribution. A structured approach to identifying key factors, evaluating relationships, and addressing barriers paves the way for informed decision-making and strategic planning. The findings offer practical guidance for improving transportation systems and operational performance within the distribution sector. Key managerial implications include:

Emphasis on human capital: Investing in the training and development of employees involved in transportation and logistics operations is essential. A skilled and motivated workforce can reduce errors, enhance operational efficiency, and improve overall performance in petroleum distribution.

Focus on lean management: Implementing lean management principles, including process streamlining, waste reduction, and resource optimization, can substantially improve operational efficiency. Promoting a culture of continuous improvement and operational excellence enables organizations to achieve cost savings and greater effectiveness in transportation logistics.

Cost reduction strategies: Developing and implementing cost-reduction strategies aimed at eliminating inefficiencies, increasing productivity, and optimizing resource utilization is particularly critical in Iran, where financial constraints imposed by economic sanctions present significant challenges. Identifying and managing cost drivers in transportation operations can enhance profitability and competitiveness. For example, adopting advanced technologies such as Transportation Management Systems (TMS) can optimize routing and reduce operational costs.

Integrated approach to addressing barriers: Given the demonstrated direct and indirect effects of transportation system barriers on lean criteria, managers should adopt a comprehensive approach to mitigating these challenges. This includes improving management practices, upgrading infrastructure, and enhancing workforce capabilities. Targeted interventions, such as implementing improved management systems and providing specialized training to address managerial and personnel-related obstacles, can substantially enhance overall system efficiency.

By focusing on key lean logistics factors, lean criteria, and identified transportation system barriers, managers can formulate strategies to reduce costs, enhance operational performance, and achieve competitive advantage. These findings are particularly relevant to the petroleum distribution sector in Iran, which faces unique challenges including economic sanctions and infrastructural limitations.

Despite its contributions, this study has several limitations. The research primarily focused on petroleum product distribution in Iran, and the findings may not be directly generalizable to other industries or regions. Additionally, the limited sample size of specialists may constrain the broader applicability of the results. Future research could examine the implementation of the identified key factors and barriers in real-world scenarios to evaluate their impact on optimizing petroleum transportation systems. Furthermore, exploring the integration of emerging technologies, such as artificial intelligence and blockchain, into transportation logistics could provide valuable insights for efficiency improvements. Comparative studies across different industries or regions may also offer useful benchmarks for enhancing transportation systems in petroleum distribution.

In light of these limitations, future studies should employ larger and more diverse samples and consider mixed-method approaches, combining quantitative and qualitative analyses, to enable more comprehensive evaluation. Such efforts could generate deeper insights into decision-making for optimizing transportation and lean logistics, particularly in areas such as cost reduction, operational scheduling, and resource allocation.

Ultimately, this study contributes to advancing knowledge in transportation management by providing a foundation for future research and supporting continued progress in operational efficiency within the petroleum distribution sector. Addressing the identified limitations, including sample size constraints, will allow subsequent research to produce broader and more impactful insights in this field.

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Nomenclature

AHP	Analytic hierarchy process
AVE	Average variance extracted
MCDM	Multi-criteria decision-making
p-value	Probability value
SEM	Structural equation modeling
t	t-statistic

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