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Designing a Pharmaceutical Supply Chain Traceability and Logistics Management Model Based on the Performance of a Resilient Green Hospital under Crisis Conditions in Greater Tehran

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Original Article

Abstract

INTRODUCTION: This study aimed to develop a model for pharmaceutical supply chain traceability and green logistics management based on the performance of resilient green hospitals under crisis conditions in Greater Tehran.

METHODS: This applied study employed an exploratory–analytical research design. Given the indefinite size of the target population, the sample size was determined using Cochran's formula for an unlimited population. Data were collected using standardized questionnaires, including the Green Logistics Management Questionnaire (Baah et al., 2019), the Supply Chain Traceability Questionnaire (Cousins et al., 2019), the Circular Economy Practices Questionnaire (Zeng et al., 2017), and the Sustainability Performance Questionnaire (Agyabeng-Mensah et al., 2020). The data were coded and analyzed using SPSS and SmartPLS software.

FINDINGS: The findings indicated that supply chain traceability has a positive and statistically significant effect on green hospital practices. Furthermore, green hospital practices significantly influence resilient performance and play a mediating role in the relationships examined. However, the direct effect of green logistics management on resilient performance was not statistically significant.

CONCLUSION: The results suggest that enhancing supply chain traceability and strengthening green hospital practices can improve the resilience and sustainability performance of hospitals under crisis conditions. The role of green logistics management appears to be indirect, primarily through its influence on green practices.

Keywords: Green logistics management; Performance; Sustainability; Pharmaceutical supply chain traceability; Resilient green hospital; Resilient performance.

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Introduction

The term "green supply chain traceability" refers to the global efforts of organizations to measure and minimize their adverse environmental impacts which the effective outcomes of these efforts can assist organizations in achieving sustainability while balancing environmental and economic performance. The American Reverse Logistics Executive Council (RLEC) defines green logistics as a method for understanding the environmental impacts of the logistics sector.

According to Wu and Dunn (1), green logistics is an environmentally responsible system that encompasses the implementation of "proactive" logistics procedures, such as the sourcing of raw materials, production, packaging, and distribution of goods, as well as reverse logistics procedures, including the collection and repackaging of waste for reuse.

A green hospital refers to an institution in which all processes, structures, and services are designed and managed based on environmental sustainability principles. Such hospitals aim to reduce operational costs, protect the environment,

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promote patient health, enhance resource productivity, and optimize energy, water, and

Logistics refers to the practices and strategies for managing the supply chain that minimize environmental and energy footprints, focusing on the transportation of materials, waste management, packaging, and distribution.

Logistics refers to supply chain management practices and strategies that seek to reduce the environmental and energy footprint of freight distribution, with particular emphasis on material handling, waste management, packaging, and transportation (1). The Natural Resource-Based View (NRBV) further explains how green products and practices can provide organizations with strategic capabilities and positive environmental outcomes (2). Extensive research in green logistics management and the circular economy supports the NRBV framework, indicating that organizations are increasingly adapting their operations to align with environmental constraints and opportunities (3).

The Ellen MacArthur Foundation (2013) conceptualized the circular economy as a regenerative system designed to replace the traditional "end-of-life" model. This approach emphasizes waste elimination through the restorative design of materials, systems, products, and business models while incorporating renewable energy sources. In practice, circular economy principles can reduce investment risks and improve risk-adjusted returns (4).

Traceability is defined as the ability to track food, feed, animals, or substances intended for consumption across all stages of production, processing, and distribution. In 2012, GS1, the international non-profit organization responsible for global barcode standards, defined traceability data elements in its Global Traceability Standard, including the identification of the traceable item, involved stakeholders, location, time, and the specific process or event undertaken (5).

Performance measurement and performance metrics are intrinsically interconnected and should not be examined independently. Existing research confirms that performance metrics play a critical role in enabling effective measurement and evaluation processes (6).

Lee et al. (2010) investigated the drivers of technological innovation through green supply chain management and found that increased technological innovation positively influences environmental performance and production material consumption, particularly under crisis conditions.

efficiency. Their findings suggest that pursuing innovation encourages the adoption of green supply chain management practices. Similarly, Lee et al. examined supply chain innovation and organizational performance in the healthcare sector, demonstrating that continuous innovation in collaboration with suppliers enhances organizational performance in large hospitals (7).

Lee et al. (2010) explored the impact of creative management practices on employee performance across multiple industries in the United States. Their results indicated that factors such as strategic partnerships, communication, and information sharing significantly improve operational performance (7).

Wisner (2006) also identified a positive and significant relationship between innovative leadership practices and organizational performance through strategic collaboration (8).

Researchers have emphasized that waste generation has significant environmental and economic consequences. Improvements in environmental performance not only reduce pollution, water consumption, solid waste generation, and the use of hazardous materials but also promote resource recovery, material reuse, and cost reduction (9). Furthermore, sustainable supply chain practices can enhance organizational competitiveness and environmental credibility, particularly when aligned with recognized environmental standards (10).

The primary objective of this study is to develop a pharmaceutical supply chain traceability and logistics management model based on the performance of resilient green hospitals in Greater Tehran under crisis conditions. The specific objectives are as follows:

- To examine the relationship between logistics management and green hospital practices.
- To assess the impact of green hospital practices on resilient green hospital performance.
- To investigate the mediating role of green hospital practices in the relationship between logistics management and resilient green hospital performance.
- To examine the relationship between supply chain traceability and green hospital practices.
- To investigate the moderating role of supply chain traceability in the relationship between logistics management and green hospital practices.

Methods

The present study is applied in terms of its objective and follows an analytical–exploratory approach. In terms of data collection, it is classified as a descriptive study of the correlational type. Regarding its nature and research approach, the study is causal, as it seeks to examine the relationships among the research variables.

Given the indefinite size of the target population, the sample size was determined using Cochran's formula for an unlimited population .In terms of data type, the study is quantitative, and the required data were collected using standardized questionnaires. The instruments employed include the Green Logistics Management Questionnaire developed by Baah et al. (2019), the Supply Chain Traceability Questionnaire by Cousins et al. (2019), the Circular Economy Practices Questionnaire by Zeng et al. (2017), and the Sustainability Performance Questionnaire by Agyabeng-Mensah et al. (2020). The collected data were coded and analyzed using SPSS and SmartPLS software.

The statistical population consists of all experts and specialists involved in the pharmaceutical supply chain and its logistics processes up to the completion of operational cycles in hospitals located in Tehran province. To determine the sample size for an unlimited population, Cochran's formula was used. A total of 150 valid questionnaires were ultimately collected.

The demographic analysis indicated that the highest frequency belonged to respondents with postgraduate education (43 individuals, 28.7%), while the lowest frequency was associated with those holding a diploma or lower qualifications (34 individuals, 22.7%).

To assess the reliability of the research instruments, Cronbach's alpha coefficient was calculated. The results demonstrated that all constructs have satisfactory reliability, with alpha values as follows in Table 1.

Table 1. Cronbach's alpha values of the questionnaires

Construct	Cronbach's Alpha
Resilient green hospital performance	0.939
Resilient performance	0.936
Pharmaceutical supply chain traceability	0.932
Logistics management	0.926

Since all alpha values exceed the acceptable threshold of 0.7, the measurement instruments are considered reliable.

Findings

In this section, a structured questionnaire was employed to measure the research variables. The instrument comprised some main constructs—green product, pollutant control, cost, environmental management, service, and quality—to evaluate green logistics performance, including a total of 18 items.

Content validity was assessed using the Content Validity Ratio (CVR), based on the evaluations of 20 subject-matter experts. The reliability of the instrument was confirmed by a Cronbach's alpha coefficient of 0.895, indicating a high level of internal consistency. Detailed results regarding the validity and reliability of all questionnaire items are reported separately.

Responses were measured on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Accordingly, the total score for each organization ranged from 18 to 90. Scores above 72 were considered favorable, scores between 54 and 72 were interpreted as moderate, and scores below 54 were classified as weak.

Table 2 presents the descriptive statistics of the study variables, including mean, median, mode, standard deviation, variance, skewness, and kurtosis. Due to space limitations, detailed statistical outputs are provided only in the table.

The results indicate that the resilient performance variable has the highest mean value (3.0373), while green logistics management and supply chain traceability exhibit the lowest mean values (2.4376), suggesting comparatively lower performance in these areas among the respondents.

Table 2. Descriptive statistics of research variables

	Resilient performance	Resilient hospital	Green logistics management	Supply chain traceability
Mean	3.0373	2.6577	2.4376	2.4376
Median	3.0000	2.4000	2.2000	2.4000
Mode	3.00a	2.00	1.00	1.00
Standard deviation	1.13478	1.14450	1.09702	1.05712
Variance	1.288	1.310	1.203	1.117
Skewness	-.070	.366	.494	.531
Kurtosis	-.874	-.803	-.697	-.268

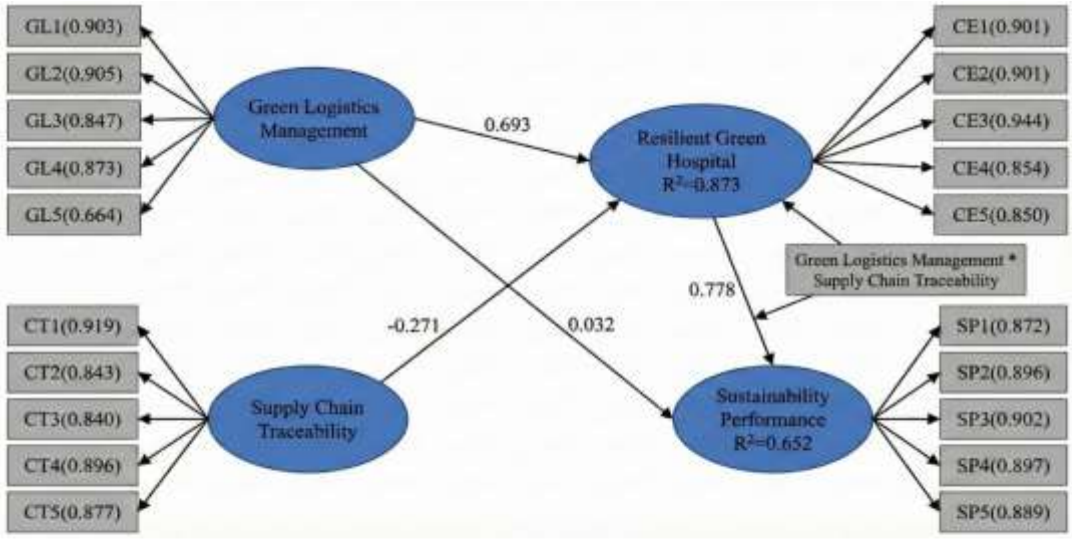

Figure 1. Factor loading values for the constructs and indicators of the research model

Table 3. Reliability and validity assessment results (Cronbach's alpha, rho_A, composite reliability, and AVE)

	Cronbach's alpha	rho_A	Composite Reliability (CR)	Average Variance Extracted (AVE)
Green hospital performance	0.939	0.940	0.954	0.804
Resilient performance	0.936	0.944	0.951	0.794
Supply chain traceability	0.932	0.940	0.948	0.785
Green logistics management	0.926	0.930	0.944	0.772

Table 4. Fornell-Larcker method

	Circular Economy Practices	Sustainability Performance	Supply Chain Traceability	Green Logistics Management
Circular Economy Practices	0.897			
Sustainability Performance	0.807	0.891		
Supply Chain Traceability	0.706	0.724	0.886	
Green Logistics Management	0.627	0.753	0.805	0.879

The results presented in Table 3 indicate that all constructs demonstrate strong internal consistency and reliability, as Cronbach's alpha and composite reliability (CR) values exceed the recommended threshold of 0.70. Additionally, the rho_A values confirm the reliability of the constructs. Furthermore, the Average Variance Extracted (AVE) values for all variables are above the acceptable threshold of 0.50, indicating adequate convergent validity. Overall, the measurement model exhibits satisfactory reliability and validity.

Model Fit Assessment

To evaluate the adequacy of the measurement model, three main criteria were assessed: internal consistency reliability, convergent validity, and discriminant validity.

First, indicator reliability was examined through factor loadings. As shown in Figure 1, all measurement items have factor loadings greater than 0.40, indicating an acceptable level of item reliability.

Reliability and Convergent Validity

Internal consistency reliability was assessed using Cronbach's alpha, rho_A (Dillon–Goldstein's rho), and composite reliability (CR). All values ranged between 0 and 1, with values above 0.70 considered acceptable. As reported in Table 3, all constructs exceed the recommended thresholds for Cronbach's alpha, rho_A, and CR, confirming satisfactory internal consistency.

Convergent validity was evaluated using the Average Variance Extracted (AVE). The AVE values for all constructs are above the threshold of 0.50, indicating that each construct explains more than half of the variance of its indicators. Therefore, convergent validity is established.

Discriminant Validity

Discriminant validity was assessed using the Fornell–Larcker criterion. According to this approach, discriminant validity is established when the square root of the AVE for each construct is greater than its correlations with other constructs. As shown in Table 4, this condition is satisfied for all constructs, confirming adequate discriminant validity.

Structural Model and Hypothesis Testing

Following the validation of the measurement model, the structural model was evaluated. The significance of the path coefficients was assessed using t-values. As illustrated in the model results, all structural paths are statistically significant (t>1.96) at the 95% confidence level, except for the relationship between green logistics management and resilient green hospital performance.

The results of hypothesis testing (Table 5) indicate that the effect of green logistics management on resilient green hospital performance is not statistically significant (t = 0.242 < 1.96). Therefore, this hypothesis is rejected. In contrast, all other hypothesized relationships are supported.

Table 5. Results of Hypothesis Testing

	Original Sample (O)	Sample Mean (M)	Standard Deviation	T-Statistic	P-Value
Green Logistics Management -> Sustainability Performance	0.032	0.021	0.131	0.242	0.809
Green Logistics Management -> Circular Economy Practices	0.693	0.686	0.099	7.009	0.000
Circular Economy Practices -> Sustainability Performance	0.778	0.787	0.124	6.277	0.000
Green Logistics Management -> Circular Economy Practices -> Sustainability Performance	0.539	0.544	0.129	4.192	0.000
Supply Chain Traceability -> Circular Economy Practices	0.271	0.277	0.098	2.763	0.006
Supply Chain Traceability * Green Logistics Management -> Circular Economy Practices	1.134	1.132	0.081	14.015	0.000

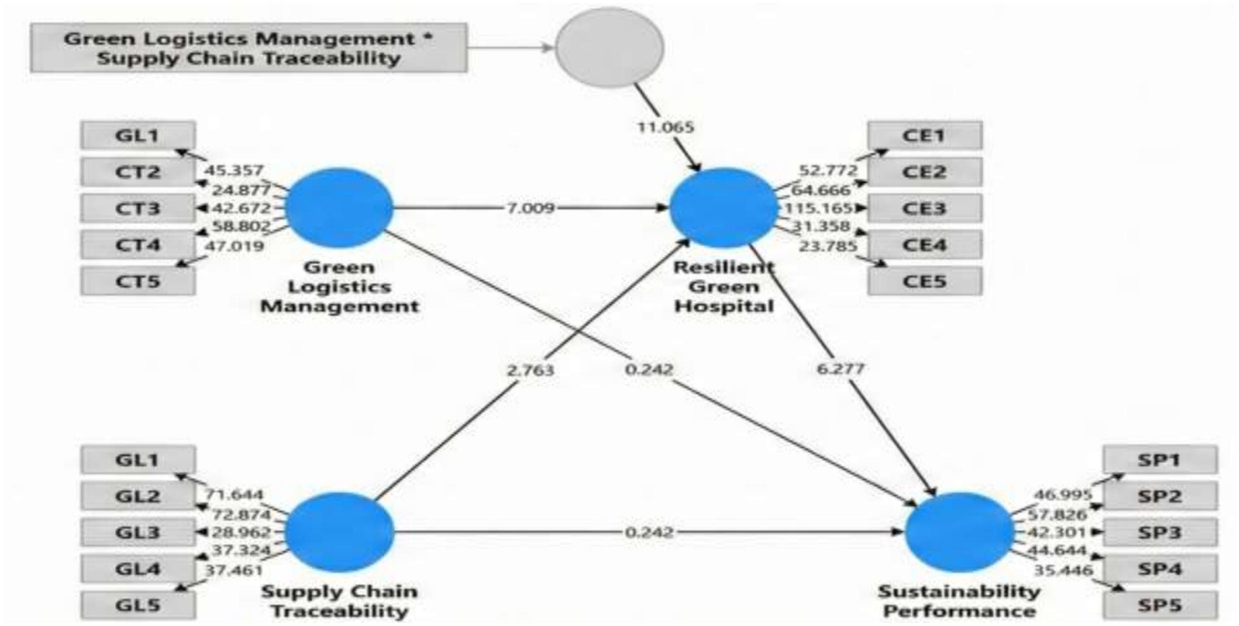

Figure 2. Z-significance coefficients (T-values)

Hypothesis Testing and Structural Model Assessment

The results of hypothesis testing are presented based on the significance of path coefficients (t-values), where values greater than 1.96 indicate statistical significance at the 95% confidence level.

The findings show that supply chain traceability has a significant positive effect on green hospital practices (t=7.009), supporting the second research hypothesis. Similarly, green hospital practices significantly influence resilient green hospital performance (t = 6.277), leading to the acceptance of the third hypothesis.

Regarding the mediating effects, green hospital practices play a significant mediating role in the relationship between logistics management and resilient performance (t= 4.192), confirming the fourth hypothesis. In addition, the mediating role of green hospital practices in the relationship between supply chain traceability and resilient performance is also significant (t =2.763), supporting the fifth hypothesis.

Overall, all hypothesized relationships are statistically significant, except for the direct effect of green logistics management on resilient green hospital performance, which was found to be insignificant.

Structural Model Fit

The structural model was evaluated using t-values (Z-statistics). As illustrated in Figure 2, all path coefficients—except for the direct path from green logistics management to resilient green hospital performance—exceed the threshold value of 1.96, indicating acceptable model fit and significant relationships among the constructs.

Discussion and Conclusion

This study aimed to develop a model of pharmaceutical supply chain traceability and logistics management based on resilient green hospital performance during crises in Greater Tehran.

The findings indicate that logistics management does not have a significant direct effect on resilient green hospital performance, as the corresponding T-value is below the critical threshold of 1.96. This result contrasts with prior studies (e.g., Centobelli et al., 2018; Khan, 2020; Trivellas et al., 2020), which reported a positive relationship between green logistics practices and organizational sustainability performance. A possible explanation is that, within the sampled hospitals, green logistics activities—such as transportation optimization, warehousing, and waste management—may be implemented at an operational level without being effectively integrated into strategic performance systems. As a result, although these practices contribute to reducing emissions, energy consumption, and resource use, they do not translate into measurable improvements in overall resilient performance.

In contrast, supply chain traceability was found to have a significant positive effect on green hospital practices, consistent with previous research (Wang et al., 2012; Kazancoglu et al., 2022). This finding highlights the critical role of traceability in enhancing transparency, accountability, and information flow across the supply chain. In this context, the integration of circular economy principles facilitates more efficient resource utilization and supports environmentally sustainable practices within hospital systems.

Furthermore, the results confirm the significant mediating role of green hospital practices in the relationship between logistics management and resilient performance, as well as between supply chain traceability and resilient performance. These findings suggest that green practices act as a key mechanism through which operational and supply chain capabilities are translated into improved sustainability outcomes. In other words, logistics management and traceability alone are insufficient; their effectiveness depends on the extent to which they are embedded within environmentally oriented practices.

In addition, supply chain traceability was found to play a significant moderating role in the relationship between logistics management and green hospital practices. This indicates that higher levels of traceability strengthen the positive impact of logistics management on the adoption of green practices. From a practical perspective, traceability systems enhance coordination, monitoring, and control across supply chain processes, thereby facilitating the implementation of environmentally friendly initiatives.

Despite these positive effects, several challenges may hinder the effective implementation of green practices, including high costs, lack of specialized skills, limited awareness, quality trade-offs, and supply chain complexity. Therefore, strengthening traceability systems can help overcome these barriers by improving visibility and decision-making, ultimately contributing to enhanced sustainable and resilient performance in healthcare systems.

Compliance with Ethical Guidelines

Ethical approval was not required for this study.

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Author's Contributions

The author was solely responsible for the conception and design of the study, data collection, data analysis, and manuscript preparation.

Conflict of Interests

None.

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