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Research Article

Simulation of the Impact of Key Variables on Smart Supply Chains Efficiency in Iran's Healthcare Industry

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Abstract

Background: The smartification of supply chains, which enables organizations to stay informed about crises in a timely manner and make appropriate decisions in response to the resulting pressures, has consistently been a crucial factor in the realm of organizational transformation. The healthcare industry in Iran faces more challenges and crises than other industries, especially due to its vital role in public health prevention and care.

Objectives: According to the reasons described, this research aims to simulate and improve the efficiency of the healthcare supply chain when confronted with crises.

Methods: In this study, the efficiency of the healthcare supply chain was simulated using the system dynamics approach and Vensim DSS.

Results: The results indicated that healthcare supply chain efficiency in Iran is unsatisfactory and may confront challenges during crises. Therefore, this study places particular emphasis on examining scenarios for improving the current situation, which stems from the consensus of experts and stakeholders in this field. In the presented scenarios, a 2% improvement in the utilization of advanced intelligent technologies and a 5% improvement in intelligent inventory management were observed. Notably, the combined effect of these two scenarios led to an overall enhancement in the average efficiency of the healthcare smart supply chain. These improvements can increase the average efficiency levels within the pharmaceutical manufacturing segment up to 1.3%, 5.8%, and 7.7% in each of the aforementioned scenarios.

Conclusions: It can be asserted that although the advancement of smart technologies and intelligent inventory management individually contribute to enhancing the efficiency of the healthcare supply chain in Iran, combining these changes can provide the groundwork for further increasing efficiency up to 7.7%.

Keywords: Smart Supply Chain; Healthcare Industry; System Dynamics; Advanced Smart Technologies; Intelligent Inventory Management; Efficiency.

1. Background

The complexity and extreme environmental fluctuations, coupled with the occurrence of unforeseen disasters and hazards, can increase the likelihood of disruptions in the hospital supply chain. Hence, enhancing the resilience of the hospital supply chain as a strategy to deal with these challenges and ensure the continuous provision of adequate and efficient services is imperative. The inability of hospitals to provide suitable and timely services can have irreparable consequences for the country; therefore, resilience in the hospital supply chain, regardless of the type of disaster, is necessary. Resilience in this context means the capacity to withstand, absorb, and respond to shocks and unexpected events that occur abruptly. Accordingly, hospitals, in times of crisis, not only need to maintain their core functions but also operate more efficiently.

Today, in line with the significant changes and the emergence of new crises in the healthcare sector, concerns among government officials and policymakers have increased significantly. In the hospital supply chain, factors such as timely drug procurement and inventory system efficiency play a vital role. Therefore, to improve the effi-

ciency of these activities, appropriate decision-making processes in inventory management are essential.

Given the considerable increase in healthcare and treatment costs and the growing demand for these services, enhancing efficiency and effectiveness has become one of the primary concerns of policymakers and government officials. Among the elements of healthcare and treatment, drugs account for about one-third of the expenses. Additionally, access to drugs can have a direct impact on community safety and health. Therefore, effective management of the hospital supply chain can provide the capability to ensure safe access to medical and pharmaceutical equipment at the lowest cost. In this regard, it should be noted that among various methods of supply chain management, inventory control is always recognized as a fundamental strategy for hospital drug management.

1.1. Theoretical Foundations of Supply Chain Management

With the globalization of markets, companies and organizations have no choice but to pursue and maintain a sustainable competitive advantage to ensure their survival. To achieve competitiveness in the supply chain, customer service must be the top priority. Nowadays, competition has shifted from inter-company competition to competition among supply chains. The supply chain always connects suppliers to manufacturers and manufacturers to potential customers. In order to compete and effectively manage the supply chain, companies and manufacturers must ensure excellent customer service, low costs, and short cycle times. In this regard, it should be noted that achieving cost advantages is not merely about product volume and economies of scale but is about supply chain management (1). Supply chain management can be considered as the integration of key business processes from the end user to the primary supplier. In other words, supply chain management supports suppliers in developing and implementing an efficient and cost-effective supply chain. It is important to note that the supply chain encompasses everything from production to product development and the required information systems to manage these commitments.

The first principle of organizational survival relies on competition and knowledge, which are among the fundamental prerequisites of the business domain. If organizations and companies ignore progress, both on the micro and macro scales, they will cede the economy and wealth production to their competitors. It should be noted that nations are competing in a new economy called the knowledge-based economy. In this type of economy, knowledge is considered the most important and fundamental resource, with learning being its primary process. Consequently, for companies to maintain a continuous and sustainable presence in the world of commerce and competition, they must plan and implement their activities around science and knowledge. Fundamental knowledge and an individual's skill, experience, and expertise are essential in this regard. Knowledge is an asset that helps the organization maintain its competitive advantage amidst rapid economic changes (2). Therefore, it can be argued that the knowledge-based economy and related foundations emphasize that, in the modern global economy, achieving and maintaining sustainable competitive advantages relies on the organization's capacity and ability to develop and effectively utilize knowledge-based resources. One of the essential topics that has been emphasized in recent decades as a driver of development is having a capable supply, production, and distribution system that operates within the framework of the supply chain.

In a competitive world and considering the complex demands of customers, organizations and companies are faced with customers who request product variety, low costs, higher quality, and quick access to products or services. Consequently, if organizations want to strive for success, they must focus on supply chain management because this approach concentrates on activities within a value chain. The prevailing perspective in this regard is that, instead of competition among companies, there should be competition among supply chains, and supply chain management is an approach to designing, organizing, and implementing these activities (3).

1.2. Measuring Supply Chain Performance

To measure the performance of a supply chain, organizations must have appropriate tools and metrics at their disposal to assess their performance relative to the type of industry in which they operate. They should also be able to compare their performance with other companies and organizations in the same field. Supply chain performance, as a key factor in the organization's success, particularly profitability, is crucial. Therefore, implementing a performance measurement system is recommended to contribute effectively to continuous improvement in the organization's performance. Given the high costs of organizations and companies in various industries on the one hand and the increasing inter-organizational competition on the other, lean production can be considered a fundamental and serious solution. A suitable supply chain implies timely production and delivery, control costs, and an efficient route from the supplier to the customer. Thus, establishing a performance measurement system in the supply chain can be an effective aid in the timely and cost-effective production and delivery of an organization. Measuring supply chain performance can be described as a process for analyzing performance management, reducing costs, reducing risk, and continuously improving value creation and operations (4).

1.3. Supply Chain in Healthcare Services and Industry

One of the primary goals of the healthcare system is to preserve and enhance the health of society. In order to achieve this, high-quality, safe, efficient, and financially secure healthcare services must be available to the public. Hospitals, as the most significant healthcare institutions, play a vital role in providing healthcare services, and their performance and costs need to be carefully considered. However, it seems that there is a significant gap between the increasing demand for high-quality healthcare services and their cost-effective and timely delivery.

In this regard, it should be noted that a significant portion of healthcare costs is allocated to the secure healthcare supply chain. Describing the healthcare supply chain, it can be said that it involves the deployment of information, equipment, and capital to serve patients. Achieving this is essential for improved clinical outcomes and cost control. It should always be kept in mind that the healthcare supply chain of a country consists of multiple disconnected parts, each of which is managed by independent and dispersed businesses. Although integration and coordination in service provision are crucial, in some cases, the importance of this issue is underestimated.

Decision-making regarding the hospital supply chain is also a critical matter, and healthcare professionals, including doctors and nurses, play a vital role in this area. The supply chain process, as an intermediary link in all programs and services provided by a hospital, is essential. Without an efficient supply chain, the provision of high-quality and cost-effective healthcare services is not possible (5).

Overall, hospitals in the country's healthcare system are divided into two main categories: government-owned and private. The government's role in the supply chain of private hospitals is often supervisory. Due to this, it can be argued that the private sector has more freedom in healthcare policy-making. Achieving this has led to increased competition among private hospitals. Although hospitals have attempted to improve their performance and increase their financial income in this regard, they have always faced challenges such as rising hospital service costs, slow supply chain delivery, low-quality inputs in the supply chain, intermediaries in the supply chain, and rising patient expectations regarding the quality of hospital services. Considering the increasing demands of hospital patients, the hospital supply chain needs to perform better in the turbulent market of this field to maintain its competitive advantage (6).

1.4. Research Background

Although numerous studies have been conducted on the smart healthcare supply chain, it should be noted that each of these studies has only examined a few aspects of the supply chain. The importance of the present research is to investigate the internal and smart dimensions of the supply chain simultaneously in a simulated manner. In the following section, we will review the distinguishing features of studies conducted in this field in comparison to the current research (Table 1).

Table 1. Features of Studies Conducted in This Field in Comparison to the Current Research

Researcher	Context of Studies	Results and Approaches				
		Cost	Trust and Loyalty	Agile Supply Chain	Sustainable Supply Chain	Smart Supply Chain
Oliveira-Dias et al. (7)	Investigating the gaps in the relationship between information and digital technologies of Industry 4.0 and agile supply chains			*		*
Riquelme-medina et al. (8)	Examining the key role of absorptive capacity and supply chain agility in engaging business ecosystems			*		
Sadeghi et al. (9)	Offering a unique and agile strategy for sustainable and resilient supply chains in the construction industry	*		*	*	
Israel et al. (10)	Investigating planning methods for integrating service supply chains and intelligent maintenance systems		*	*		*
Nili-Pour Tabatabai et al. (11)	Focusing on optimizing the use of information technology in supply chain management			*		

Rah-chamani et al. (12)	Designing a model for smart service supply chains using data-driven methods					*
Rashidi Torbati et al. (13)	Internet of things-based smartening of supply chains in IT and telecommunications companies in Tehran province			*		
Kazancoglu et al. (14)	Examining the role of resilience, agility, and responsiveness in sustainable supply chains during the COVID-19 pandemic	*		*		
Fakhrzad et al. (15)	Presenting a mathematical model in smart supply chains based on ICPT in an MTS environment		*			*
Sargazimoghadam and Shahsavari (16)	Reviewing the role of intelligent software factors in supply chain management			*		
Current study	Title of the present research	*	*	*	*	*

In this study, all dimensions were comprehensively considered, including cost, sustainable supply chain, smart supply chain, and trust and loyalty, which aligns with previous research.

2. Objectives

This research aimed to simulate and improve the efficiency of the healthcare supply chain when confronted with crises.

3. Methods

Due to the absence of a pre-established conceptual model in this field, the stages and methods used to extract the model have been carried out in four steps, as follows: (1) Extraction and identification of indicators: In the initial step, experts and specialists were consulted to extract and identify indicators, along with a review of the theoretical foundations of the research. (2) Model validation: In the next step, the model was validated to ensure its accuracy in defining relationships and formulating them. (3) Model implementation: The model was then implemented with care, and after confirming its validity, it was simulated and analyzed based on various policies.

It is important to note that the Vensim DSS software was employed in this research to design the model and extract outputs. Additionally, in order to provide a rich visual representation that forms the basis of the model, an initial presentation was made based on system dynamics methodology.

The selection criteria for experts included the following: (1) At least ten years of continuous experience in the healthcare industry of the country; (2) familiarity with the healthcare supply chain in the country; and (3) a comprehensive understanding of intelligent supply chain concepts.

3.1. Definition of Key Variables and Cause and Effect Relationships of the Research

3.1.1. Internal Drug Production Reinforcement - Sanctions (R1)

With an increase in domestic drug production by local manufacturers, drug sanctions will become more pronounced. This will lead to a decrease in the number of canceled drug sales orders. The resulting change will increase the drug supply. The increased supply of Iranian drugs to the market is expected to boost achieved sales rates, ultimately reducing lead time pressure. Reduced lead time pressure will result in a decreased number of canceled purchase orders, leading to an increase in drug demand. Increased drug demand will, in turn, prompt an increase in the production of Iranian drugs and their reentry into the market (Figure 1).

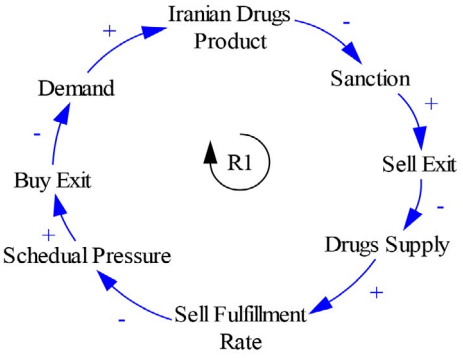


Figure 1. Internal drug production reinforcement - sanctions loop (R1).

3.1.2. Internal Drug Production Reinforcement - Demand (R2)

As domestic drug production by local manufacturers increases, the number of canceled sales orders will decrease, leading to a change in drug supply in the opposite direction of the change above. Consequently, an increase in drug supply will result in higher purchase order rates, along with a subsequent increase in drug demand. This increase in demand will provide the grounds for increased domestic drug production by local manufacturers (Figure 2).

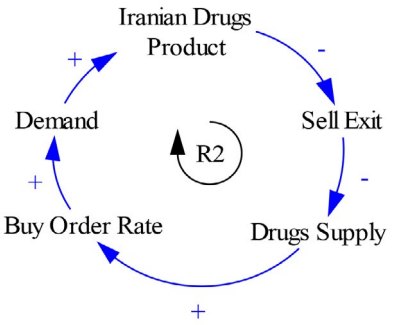


Figure 2. Internal drug production reinforcement - demand loop (R2).

The balancing loop, as depicted in Figure 3, signifies that an increase in drug supply will lead to an increase in the rate of purchase orders. With the introduced change in the purchase order rate, demand and, consequently, lead time pressure will increase. With increased lead time pressure, we will witness an increase in the number of canceled sales orders, resulting in a reduction in drug supply. The balancing loop, as depicted in Figure 4, indicates that an increase in drug supply will create grounds for an increase in the rate of sales orders. In line with the introduced change, it is expected that lead time pressure will also increase, leading to an increase in the number of canceled sales orders and, consequently, a reduction in drug supply in the market.

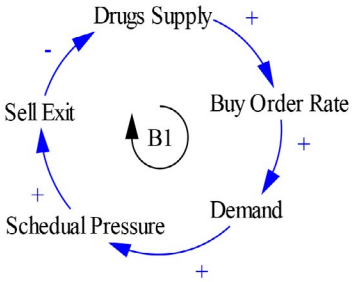


Figure 3. Drug supply - drug demand balancing loop (B1)..

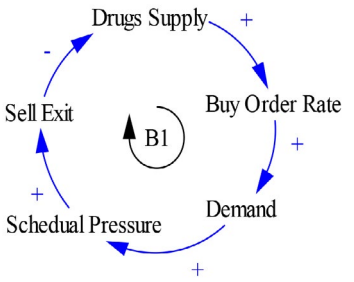


Figure 4. Drug supply balancing loop (B2).

An explanation of some of them has been provided in the above section due to the diversity of loops in the model. Figure 5 presents the conceptual model of the research within the framework of a cause-and-effect diagram.

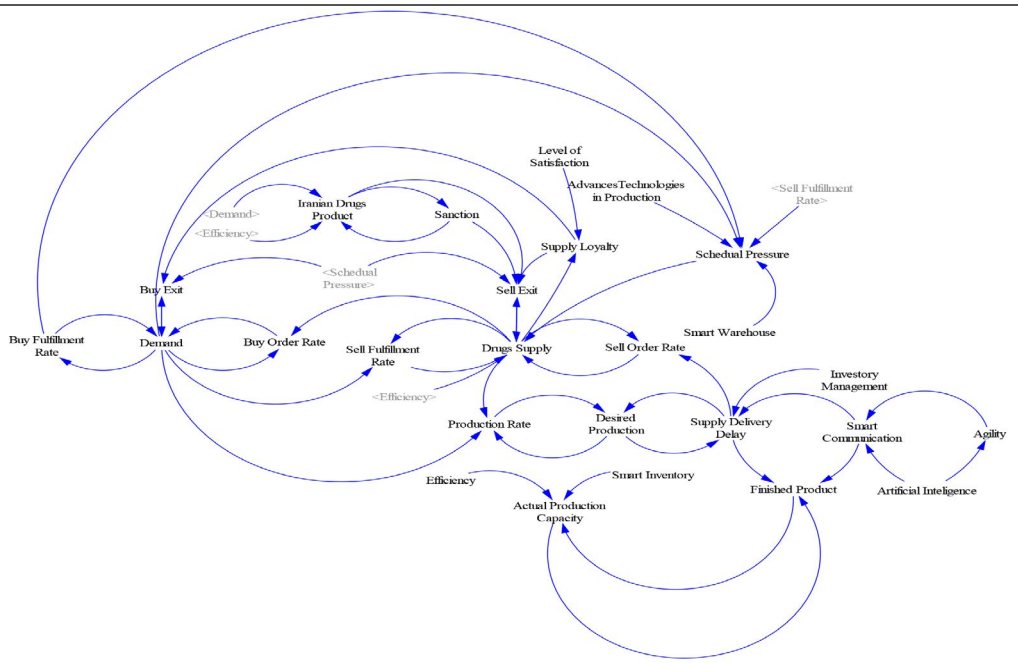


Figure 5. Cause-effect diagram.

4. Results

4.1. Behavior Reproduction Test

A behavior reproduction test was used to ensure the accuracy of the simulated model. In this test, we compare simulation results with available data from the past. The results from Figures 1 and 2 support the idea that the simulated model effectively replicates the behavior of the variables under investigation concerning the production of domestic drugs and the efficiency of pharmaceutical companies in Iran during the mentioned period. In the following plots, the values of "Iranian drugs product" and "efficiency in Iranian drugs co." represented in red correspond to the simulated behavior. In contrast, the values marked as "current" in blue represent the actual behavior of the variables in question (Figures 6 and 7).

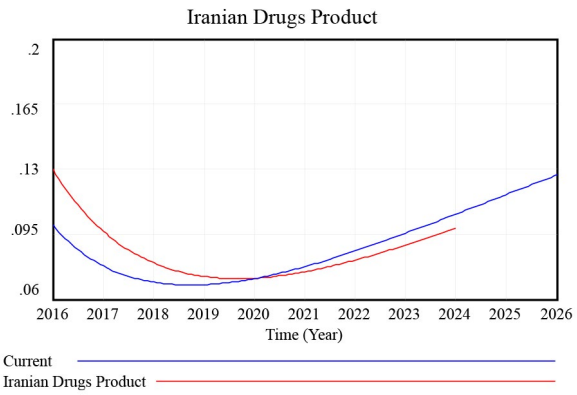


Figure 6. Behavior reproduction test for the domestic drug production variable.

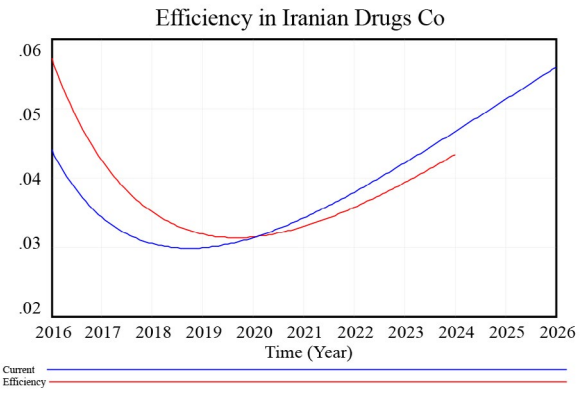


Figure 7. Behavior reproduction test for the efficiency of Iranian drug companies variable.

4.2. Sensitivity Analysis Test

The sensitivity analysis test in the system dynamics examines how sensitive key variables in the research are to the examined parameters. In this section, selected parameters that directly affect the variables are changed within a defined spectrum to examine their effects on the variables. In this regard, the sensitivity of the variables "domestic drug production" and "efficiency of Iranian drug companies" to changes in advanced technologies in Iran's pharmaceutical industry was investigated. These parameters were altered by ± 5%. The results of the sensitivity analysis indicated that a 5% change in advanced technologies in the pharmaceutical industry would likely cause "domestic drug production" and "efficiency of Iranian drug companies" to be, on average, approximately 1.5% more in the yellow region, 5% more in the green region, 7% more in the blue region, and 10% more in the gray region, as represented in the graphs (Figures 8 and 9).

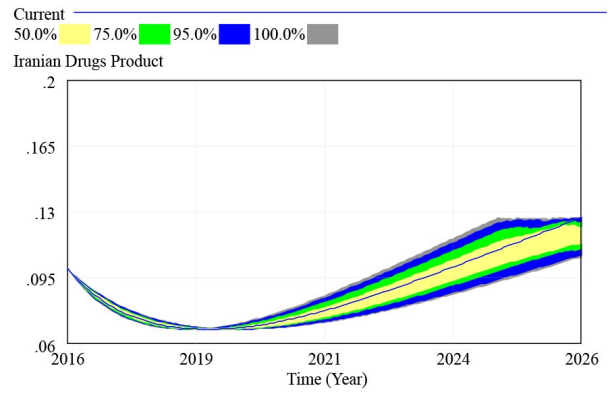


Figure 8. Sensitivity analysis test for the domestic drug production variable.

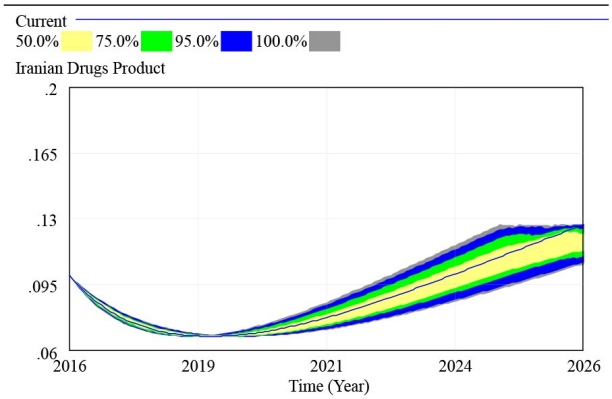


Figure 9. Sensitivity analysis test for the efficiency of Iranian drug companies variable.

4.3. Policy Making for Optimization of Key Variables

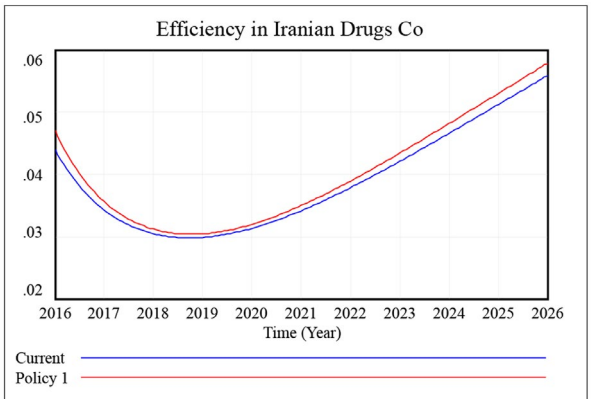
Aligned with the simulations conducted in the following section, potential policies for improving the efficiency of the pharmaceutical supply chain in Iran were investigated. It is important to note that the scenarios examined in this context were developed in line with the

opinions of experts in this field.

4.3.1. Scenario 1

Forecast a 2% increase in advanced intelligent technologies in the drug production sector during the study period and assess its impact on the efficiency of drug manufacturers in Iran.

According to the results of the simulation, a 2% increase in advanced intelligent technologies in the drug production sector during the study period will lead to an average increase of about 1.3% in the efficiency of drug manufacturers during the study period. It should be noted that the red curve in the graphs presents the implementation of the scenarios examined (Figure 10).



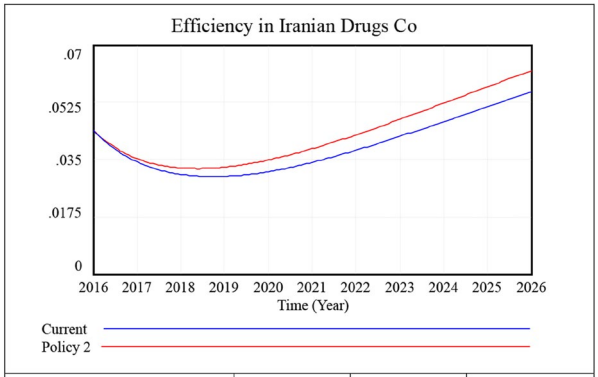
Year	Base Values	Scenario	Changes %
2024	0.4661	0.4817	1.56
2025	0.5123	0.5302	1.79
2026	0.5586	0.5785	1.99

Figure 10. Forecasting a 2% increase in advanced intelligent technologies.

4.3.2. Scenario 2

Forecasting a 5% improvement in intelligent inventory management in the drug production sector during the study period and assessing its impact on the efficiency of drug manufacturers in Iran.

According to the results of the simulation, a 5% improvement in intelligent inventory management in the drug production sector during the study period will lead to an average increase of approximately 5.8% in the efficiency of drug manufacturers during the study period. (Figure 11)



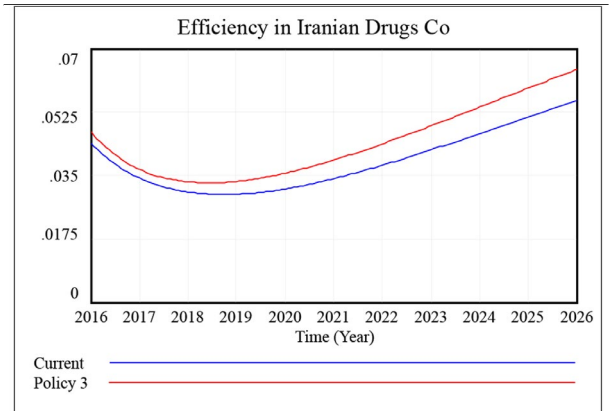
Year	Base Values	Scenario	Changes %
2024	0.4661	0.5221	5.6
2025	0.5123	0.5721	5.98
2026	0.5586	0.6217	6.31

Figure 11. Forecasting a 5% improvement in intelligent inventory management.

4.3.3. Scenario 3

Forecasting a 2% increase in advanced intelligent technologies in the drug production sector and a 5% improvement in intelligent inventory management in the drug production sector during the study period and assessing their combined impact on the efficiency of drug manufacturers in Iran.

According to the results of the simulation, a 2% increase in advanced intelligent technologies in the drug production sector and a 5% improvement in intelligent inventory management in the drug production sector during the study period will lead to an average increase of about 7.7% in the efficiency of drug manufacturers during the study period. (Figure 12)



Year	Base Values	Scenario	Changes %
2024	0.4661	0.5389	7.28
2025	0.5123	0.5911	7.88
2026	0.5586	0.6427	8.41

Figure 12. Forecasting a 2% increase in advanced intelligent technologies in the drug production sector and a 5% improvement in intelligent inventory management.

5. Discussion

This study focused on evaluating the performance of pharmaceutical manufacturers within the country's healthcare supply chain, employing a system dynamics approach. In the initial step, after identifying the influential variables, the model's boundaries were defined. Subsequently, causal relationships between the main research variables were identified to develop the final research model. After completing these steps and validating the simulated model's reliability and validity, the gap between the desired and current states was examined. The results were then adjusted and modified based on various proposed scenarios to enhance the efficiency of active pharmaceutical manufacturers in the healthcare supply chain.

Based on the findings of this study, it can be concluded that if the use of advanced intelligent technologies in the pharmaceutical production sector and intelligent inventory management in the healthcare supply chain is improved, it will pave the way for increased efficiency among pharmaceutical manufacturers. In the scenarios presented, the investigation proceeded by first examining a 2% improvement in the use of advanced intelligent technologies and then a 5% improvement in intelligent inventory management on the efficiency of pharmaceutical manufacturers in the country's healthcare supply chain. The results of these scenarios suggest that these changes would provide the groundwork for improving the efficiency of the healthcare supply chain in the country by 1. 3% and 5.8%, respectively. In the final scenario, the combination of the above scenarios was also examined. According to the results obtained from this simulation, the combination of these two scenarios could potentially lead to an average 7.7% improvement in the efficiency of pharmaceutical manufacturers in the country's healthcare industry over the study period.

Considering the three scenarios proposed to enhance the efficiency of pharmaceutical manufacturers in the healthcare supply chain, the best performance was achieved by implementing the combined scenario of improving the use of advanced intelligent technologies and intelligent inventory management in the pharmaceutical production sector. In this regard, it is recommended that policymakers and manufacturers engaged in this field focus on improving intelligent inventory management and the use of advanced intelligent technologies to enhance efficiency and create a conducive environment to reduce the gap between the current and desired situations. Furthermore, other researchers are encouraged to improve the model further and extract causal relationships between newly identified variables to conduct future research for a more accurate prediction of pharmaceutical manufacturers' efficiency in the country's healthcare industry.

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Conflict of Interests:

There is no conflict of interest.

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