Research Article

Simulating Flexibility of the Smart Supply Chain in Iran's Health Industry Using System Dynamics Approach

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Abstract

Background: Making a smart and digital supply chain has always been a key phenomenon and a vital factor in organizational transformation. This can play a key role in a country's health industry. The output can help policymakers check the smart supply chain's flexibility level and then provide a basis for improving flexibility in the health industry by presenting possible scenarios.

Objectives: This study aims to improve the flexibility of the smart supply chain using the system dynamics method by improving intelligence variables.

Methods: This study used the system dynamics approach and VENSIM DSS to extract and present a dynamic model to investigate and indicate the smart supply chain's flexibility in Iran's health industry. The gap between the current and desired situations was identified, and then by implementing possible scenarios, which have been taken from experts' opinions, steps were taken to improve the supply chain's flexibility.

Results: Based on the results, smart supply chain flexibility in Iran is unfavorable and probably faces many problems in providing medicine and health services. Under possible scenarios, the highest level of smart supply chain flexibility in Iran's health industry relies on the institutionalization of smart warehouses or smart communication by 5% during the period under review. This can increase the average smart supply chain flexibility level to 2.08% and 1.4%, respectively.

Conclusions: According to the scenarios, policymakers can provide the groundwork for improving the flexibility of the supply chain of the health industry by changing one of the two variables of smart warehouse and smart communication.

Keywords: Simulation; Smart Supply Chain; Flexibility; Health Industry; System Dynamics

1. Background

Due to rapid global changes and advancements in information technology and its applications across various industries and services, firms have acquired various capabilities such as establishing diverse and numerous communications, combining capabilities and competencies, fast and diverse movements, and agile activities. With simple and abundant access, and without time and place restrictions, regardless of business processes and related computer systems, today's organizations must move from the static and slow state of today's businesses to dynamic and fast frameworks. Traditional approaches in business involve a huge amount of cost due to the inability to provide complex and diverse products and the lack of timely and fast delivery of products and services. However, new approaches seek to provide the services and products needed for the changing global markets based on the combination of traditional business networks, communication, and work interactions with the help of information and communication technology (1).

Iran's developing economy is facing many problems in the goods distribution system. Its non-compliance and unbalanced growth with other dimensions and components of the national economy, such as the production and consumption system, are evident. The goods required by the market are presented to consumers with improper packaging and prices several times the cost price, with improper coverage and distribution.

The supply chain in healthcare differs from other supply chains in several areas. Hospitals and medical centers consume more energy compared to other service institutions. Hospitals are among the waste production sources in cities, and cost plays an important role in their performance. Due to the provision of services to patients and the high number of employees compared to other services, healthcare has a high social impact on society. The satisfaction of stakeholders, especially patients, is one of its challenges (2). The health system has one of the most complex and sensitive supply chains globally. Dealing with human lives and health is considered a risk-prone system. Therefore, providing health items and medical equipment as soon as possible is one of the most critical challenges. Failure to provide a device and tool for surgery or medicine can be fatal (3).

Meanwhile, compared to other industries, the healthcare industry has been slower to accept successful supply chain techniques and has less coherence and coordination in its supply chain. Under the influence of the intensifying competitive environment in supply chain management, one can see organizations' increasing attempts to improve the supply chain's effectiveness and performance. The intelligentization of the supply chain, under the influence of the emergence of the fourth industrial revolution and progress in information technology at different levels, can have a significant effect on its overall performance and lead to a favorable response to the continuous changes in the business environment in the wide network of local and global supply chains (4).

In recent years, efforts have been made to eliminate the distance and control of the supply and distribution process, including creating direct supply locations. However, this product distribution system in our country lacks sufficient effectiveness and efficiency due to the growing trend of urbanization and the developing nature of the Iranian economy. The point neglected in the design and implementation of these plans, arguably, is supply chain management. Examining and studying the world's successful companies shows that the main factor in their success is the intelligent management of their supply chain. All of them have designed, integrated, and intelligent supply chain management, supply, and sales systems. Based on this, one of the basic requirements in managing various industries and organizations is having intelligent and integrated systems to manage the supply and demand chain in the country (5). A company should turn smart if it wants to benefit from service opportunities, seek to create a coherent, efficient, and effective network of raw materials, supply and producers, distributors, wholesalers, retailers, and consumers, be the final suppliers, and at the same time be equipped with an integrated and smart system to manage the entire chain.

Buyer markets have replaced seller markets, and customer needs and preferences are becoming increasingly diverse. As a result, supply chain management systems have become more complex. Additionally, new requirements have arisen due to mass production, manufacturing to order, flexibility, agility, direct communication with suppliers and customers, and rapid environmental changes. Based on this, more attention has been paid to using agents to solve these problems in software environments (6). Therefore, using smart software agents in supply chain management can improve management in this field.

A centralized and linear approach often limits traditional supply chain management. This is due to the limitations in effective cooperation of the members involved in the chain and the difficulty of adapting to the external dynamic environment. In recent years, information technology, including databases, applications, software, and communication networks, has been widely used in supply chain management to improve performance. These technologies have solved problems such as information sharing and order management. However, many smart activities, such as negotiation, decision-making, and cooperation between chain members, must be improved and developed. Smart agents have a high potential to improve the performance of the supply chain and solve the above problems. Using smart agents in the supply chain increases its flexibility and capabilities to react to changes in each component. This can positively affect order time, human process time, inventory levels, and the frequency of stock shortages. Agents can play a role on behalf of the supply chain members by using the characteristics of independence and decision-making power (7).

In industrial environments, effective supply chain management is not just about improving the effectiveness of business activities; cost reduction can also play an important role in chain effectiveness. In manufacturing a product, the initial design is much more important than reducing costs during the production cycle. One of the most critical parts of product design is how the designer gathers information. As a result, there is a need for a system in the design stage to search for information effectively. The supply chain's production cycle can be divided into four stages: Supply of raw materials, product design, production, and distribution. As we move through each stage, the cost of development increases significantly. Therefore, it is essential to focus on the initial plan to optimize the development of the new product. Information infrastructure has been developed to support design in supply chain management in the intellectual web service environment. This infrastructure can provide consistent service interfaces for integrated design features for agents and general users. The design support agent as a client for this infrastructure helps designers find desired and appropriate information from many sources in the supply chain. This factor has two basic search functions and another inference to provide designers with solutions (8).

The bullwhip effect is considered an undesirable phenomenon for the supply chain. It is caused by the fact that product output is often more than the demand of the final customer, increasing storage costs, stagnation of capital, and inefficiency of the supply chain. To curb this problem, a comprehensive model of the supply chain with a different number of variable factors stochastic-neural-fuzzy genetic algorithm cost models are used

(9-11). A method to reduce the bullwhip effect has been described, which uses agents and reinforcement learning. In this model, upon receiving an order from the customer, each node in each category makes decisions based on the previous level buyer to increase profits or reduce costs. Each node must pay a maintenance fee based on the inventory level. As a result, if the order of a node is more than the requirement of the previous level node, it must bear the storage cost. If it is less than the demand, it must pay a fee. The main challenge in designing a reinforcement learning system is to define the incentive function to calculate the reward agents receive as feedback for their actions (12).

The importance of this research is that it examines the flexibility of the supply chain in the healthcare industry during crises, and it is possible to provide scenarios to increase the flexibility of the supply chain by modeling the incident in this regard.

1.1. Review of the Literature

To investigate the role of artificial intelligence in supply chain management, Toorajipour et al. (13) systematically reviewed the subject's theoretical foundations. Their findings suggested that techniques such as fuzzy artificial neural networks, multi-agent systems, and genetic algorithms had been applied more widely than other methods. They also highlighted that the network-based nature of supply chain management and logistics offered a natural framework for implementing artificial intelligence.

The smart supply chain model presented in Oh and Jeong's review study (14) emphasized financial and structural flexibility and their realization by the various components of the supply chain, including suppliers, manufacturers, distributors, retailers, customers, facilitators, machines, products, and systems. It also incorporated the components of information, communication, and production technologies (ICPT), such as the Internet of things, big data analysis, cloud computing, cyber-physical systems, 3D printing, smart factories, artificial intelligence, robotics, virtual and augmented reality. The study noted the convergence of technologies in industries such as smart factories, smart logistics, and smart retail, where all components physically and virtually interact with each other and share data to meet customer needs. Due to these characteristics, the system should be flexible and, based on the development of mathematical models, introduce real-time solutions such as determining alternative routes, changing capacity, changing chain members, and controlling supply quantities.

Israel et al. (15) investigated a planning method for integrating service supply chains and intelligent maintenance systems. Their research aimed to present a method that integrates intelligence into operational planning to reduce costs and ensure supply chain service levels.

Nilipor Tabatabaei et al. (16) optimized the use of information technology in supply chain management. Their research indicates that optimizing the application of information technology can reduce time and cost and improve the efficiency of the supply chain.

Rahchamani et al. (17) designed a model for the smart supply chain of services using the foundation data method. The most important categories identified include the flow of smart information, the flow of smart financial resources and information technology, smart communication, transparency, sharing, and expert human resources.

The results of Rashidi Torbati et al.'s (18) research, titled "smart supply chains with the Internet of things approach" (case study: Companies active in ICT in Tehran province), confirm that the use of IoT will increase the speed of adaptation and environmental adaptability of the supply chain of the companies under investigation.

In their research, Mohammadian et al. (19) ranked the factors affecting agile and green supply chains in e-commerce, considering the application of IoT. They extracted the factors affecting agile and green supply chains and the smart retail supply chain tools in the IoT platform. Then, by using pairwise comparisons and network analysis methods, they determined the importance of each index and set the options. Their results suggest tracking customers' behavior is more important than other extracted options.

Fakhrzad et al. (20) presented a mathematical model for a smart supply chain based on ICPT in an MTS environment. To address traditional supply chain problems, they considered a supply chain based on ICPT called a smart supply chain in an MTS production environment, including four levels of producer, warehouse, distributor, and customer, aiming to maximize profit and minimize preparation time. They presented a mixed-integer nonlinear model for this problem, solved a sample problem using the enhanced epsilon constraint method in GAMS software, and analyzed the results. They also examined two scenarios of increasing demand and adding a new product, confirming the model's correctness and the proposed method's efficiency.

2. Objectives

This study was conducted to improve the flexibility of the smart supply chain using the system dynamics method by improving intelligence variables.

3. Methods

Due to the study's exploratory nature, a predetermined conceptual model was unavailable. The steps and methods employed in this study can be summarized in the following steps:

In the first step, interviews and open-ended questionnaires were conducted to gather suitable variables from the experts' perspectives. The initial conceptual model was adapted, modified, and presented based on their opinions. It is worth noting that the selection criteria for the experts included:

1. At least ten years of experience in the country's health industry.

2. Familiarity with the smart supply chain in the country's health industry.

3. Comprehensive understanding of smart supply chain issues.

The second step involved validating the model to ensure its accuracy in defining and formulating relationships. Various tests, such as model structure tests, model behavior tests, and policy consequences tests, were conducted for this purpose.

Moving on to the third step, the model was implemented. Once the validity of the designed model was confirmed, simulation and analysis of the model's behavior were performed using different policies.

Various methods were employed to identify appropriate and effective variables, including reviewing relevant studies, examining records, utilizing expert opinions, and conducting targeted interviews and open questionnaires with experts in the field.

It is important to mention that the VENSIM DSS software was utilized in this study for model design and output extraction. Furthermore, a detailed and comprehensive visual representation was initially created to present a system dynamics-based model.

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

The system dynamics approach visualizes the relationships between variables using reinforcing loops and balancing loops. These loops represent the cause-and-effect dynamics within the model. However, given the abundance of cause-and-effect loops in this research, only the main and significant loops are described. Reinforcing loops are denoted by "R," while balancing loops are denoted by "B."

The balancing loop B1, as shown in Figure 1, illustrates that an increase (or decrease) in the desired production rate leads to a subsequent decrease (or increase) in supply delivery delays. This change in supply delivery delays, in turn, influences the expected production rate in the opposite direction. On the other hand, the balancing loop B2 demonstrates that an increase (or decrease) in delivery delays from the supplier leads to a decrease (or increase) in the production rate due to the accumulation of delays. Furthermore, this issue amplifies the delay in delivery from the supplier.

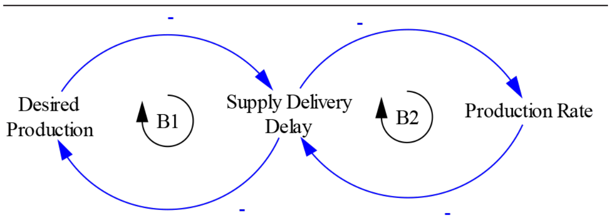


Figure 1. Balance loops and supply delivery delay

Loops reinforcing behavioral distortions - the market sentiment indicator are shown in Figure 2. According to Figure 2, any intensification (decreasing) of behavioral biases (abnormal behavior biases, perceptual biases, cognitive biases, intuitive biases, emotional biases) causes a change in the market sentiment index, which aligns with the changes in the aforementioned behavioral biases. In other words, it can be said that the aggravation (decrease) of each behavioral bias leads to the improvement (decrease) of the market sentiment index. Conversely, behavioral biases also change in line with changes in the market sentiment index. In this regard, it should be pointed out that the market sentiment index is an index that measures the willingness to accept risk from the investors' point of view. Therefore, it is strongly influenced by behavioral biases. Other loops in the figure below can be called reinforcing loops of behavioral distortions. The loops confirm that if one of the behavioral strains deteriorates, the others in society can be damaged.

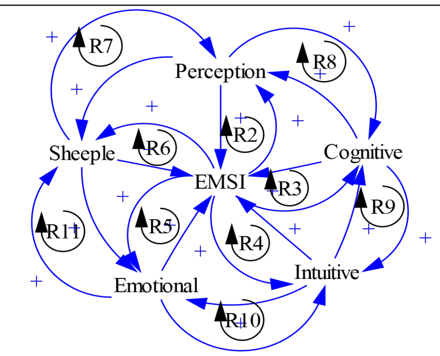


Figure 2. Reinforcement loops of behavioral distortions - market sentiment index

The reinforcing loop R1 illustrated in Figure 3 emphasizes the relationship between the efficiency of smart ordering and various factors, including satisfaction levels, complaints, and cost. When the efficiency of smart ordering increases (or decreases), it leads to an increase (or decrease) in satisfaction levels and a decrease (or increase) in the number of complaints. This, in turn, results in a decrease (or increase) in the cost of services and resources. As this cycle continues, the efficiency of smart ordering further improves (or declines). It is crucial to note that satisfaction directly influences the efficiency of smart ordering. Therefore, when there is an increase (or decrease) in satisfaction levels, a corresponding change in the efficiency of smart ordering can be observed.

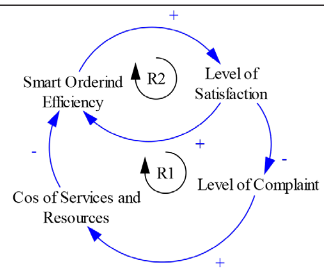


Figure 3. loops reinforcing the smart ordering efficiency

Based on the description in the above section that examines the main loops of the research, the conceptual model of the research can be presented in the framework of the stock-flow diagram of Figure 4.

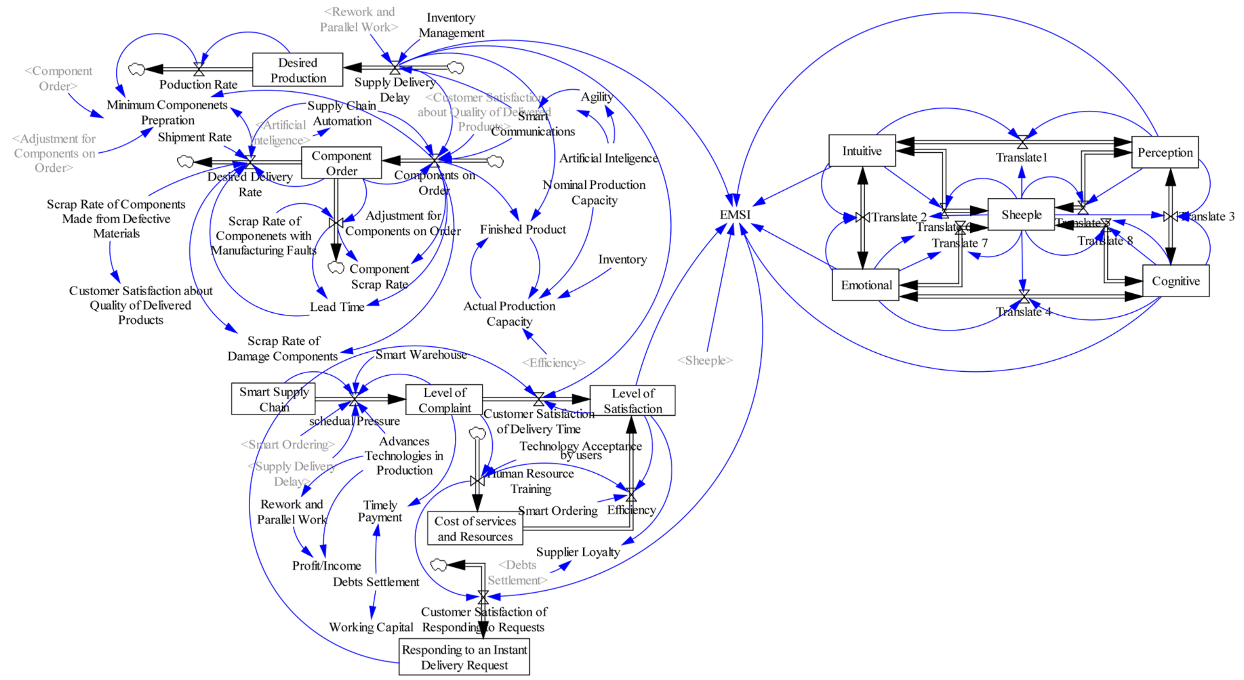


Figure 4. Diagram of research stock and flow

4. Results

4.1. Behavior Reproduction Test

Retesting was used to ensure the accuracy of the simulation model performance. The results from graphs 1 and 2 confirm the simulation of the smart supply chain in the mentioned period. In the graphs below, the smart supply chain and desired production values in red confirm the simulated behavior, and the current values in blue confirm the actual behavior for the desired variable (Figures 5 and 6).

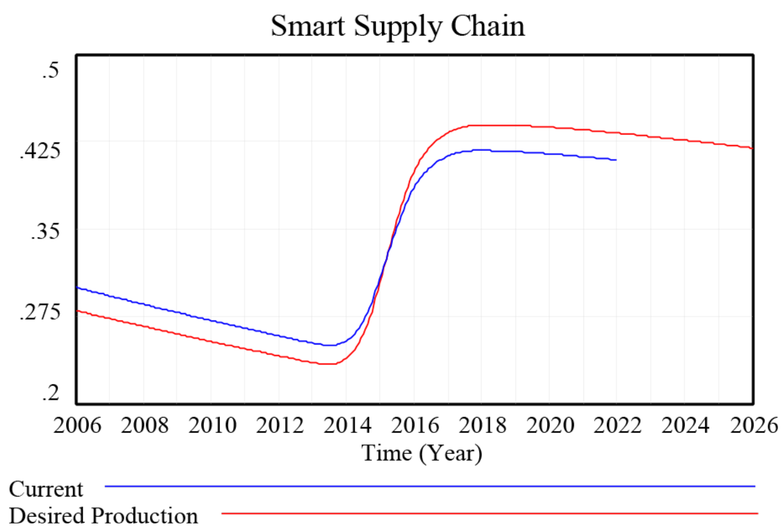


Figure 5. Behavior Reproduction Test of the smart supply chain variable

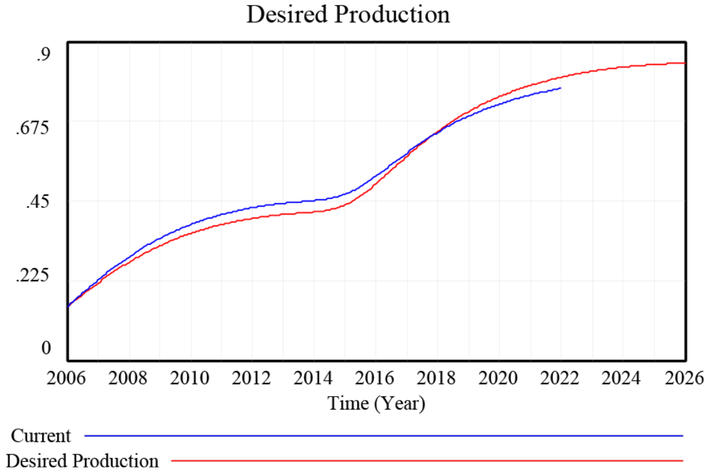


Figure 6. Behavior Reproduction Test of the production rate variable

4.2. Sensitivity Analysis Test

This section investigated the sensitivity of the desired production rate and smart supply chain to changes in production capacity. To achieve this, the mentioned parameters were changed by ±10%. The results confirmed that a 10% change in the production capacity caused the expected production level and the flexibility of the smart supply chain with a probability of 50 to 100 percent in the color areas, as shown in Figures 7 and 8.

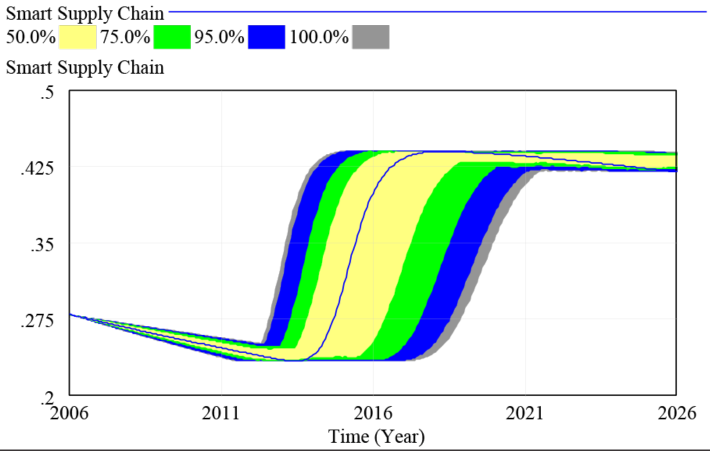


Figure 7. Sensitivity analysis of smart supply chain variable

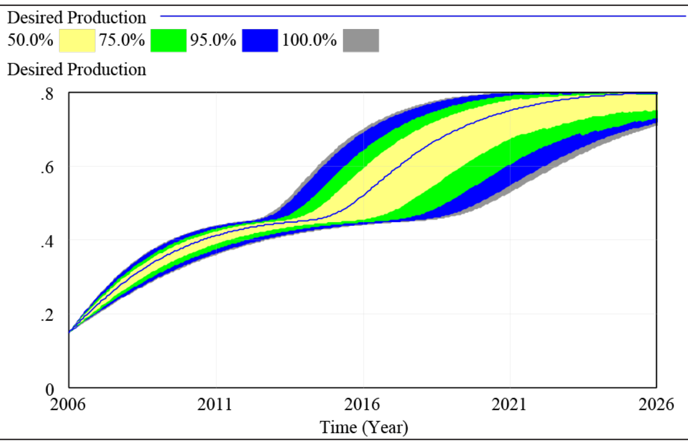


Figure 8. Variable sensitivity analysis of production rate

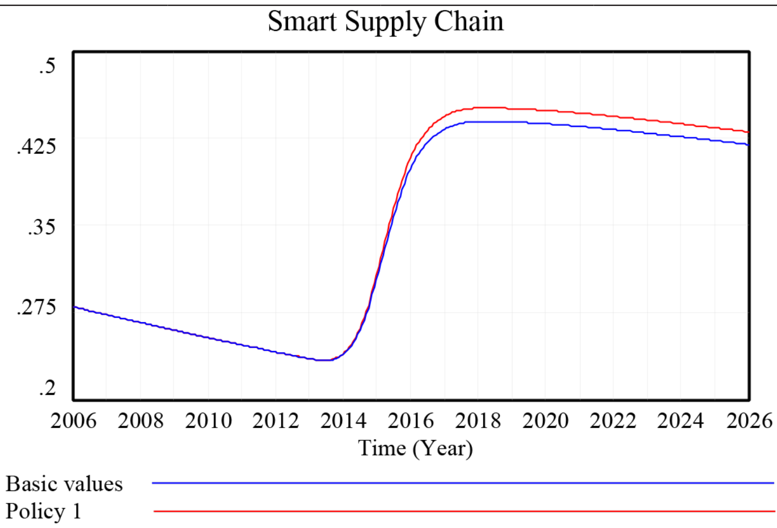
4.3. Optimization of the Key Variables of the Model by Making Policies

This section investigated possible scenarios regarding improving the flexibility of the health industry's smart supply chain in the country. In this regard, it should be noted that the presented scenarios are based on experts' opinions in this field.

4.3.1. Scenario 1

Predicting a 5% increase in smart communication from 2006 to 2026 and its effect on the flexibility of the smart supply chain.

Based on the simulation results, implementing a 5% improvement in smart communication will enable the flexibility of the smart supply chain in the health industry to increase by 1.4% on average during the period under review. As seen in Figure 9, the red curve in the presented diagrams confirms the performance of the examined scenarios.

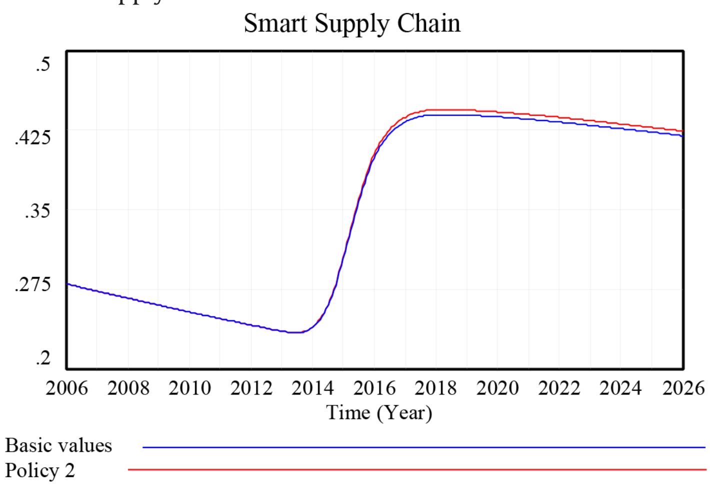


Year	2023	2024	2025	2026
Basic values	0.4293	0.4261	0.4229	0.4195
Scenario 1	0.4406	0.4373	0.4339	0.4304

Figure 9. Prediction of a 5% upgrade of smart communications and its effect on the flexibility of the smart supply chain

4.3.2. Scenario 2

Based on the simulation results, it is predicted that implementing a 2% improvement in supply chain automation from 2006 to 2026 will lead to an average increase of 0.62% in the flexibility of the smart supply chain in the health industry during the specified period (Figure 10).

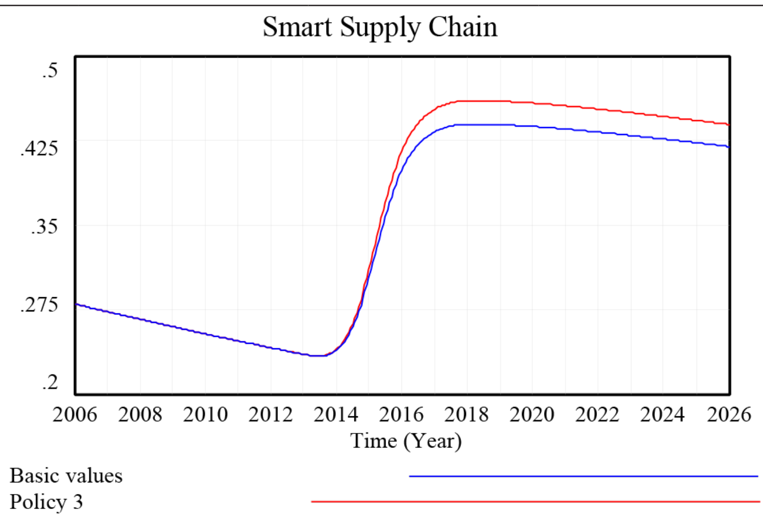


Year	2023	2024	2025	2026
Basic values	0.4293	0.4261	0.4229	0.4195
Scenario 2	0.4338	0.4306	0.4273	0.4239

Figure 10. Prediction of 2% improvement of supply chain automation and its effect on the flexibility of smart supply chain

4.3.3. Scenario 3

Based on the simulation results, it is predicted that the implementation of a 5% upgrade of the smart warehouse from 2006 to 2026 will result in an average increase of 2.08% in the flexibility of the smart supply chain in the health industry during the specified period (Figure 11).

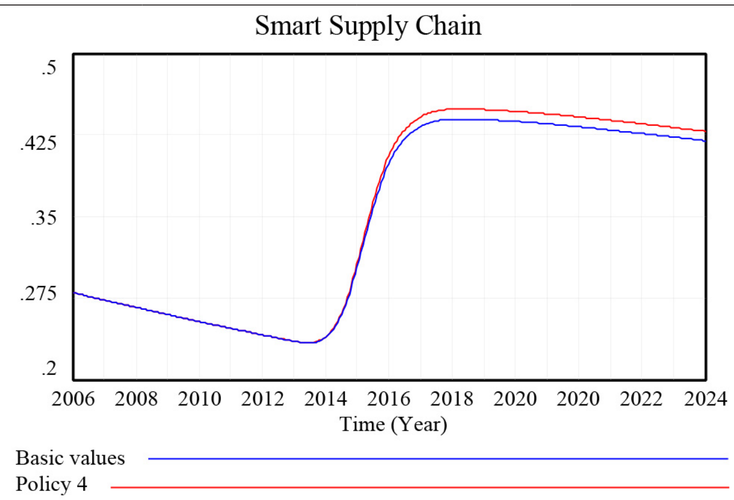


Year	2023	2024	2025	2026
Basic values	0.4293	0.4261	0.4229	0.4195
Scenario 3	0.4496	0.4462	0.4427	0.4391

Figure 11. Prediction of 5% upgrade of smart warehouse and its effect on the flexibility of smart supply chain

4.3.4. Scenario 4

Based on the simulation results, it is predicted that a simultaneous 5% improvement in smart communication and smart warehouse, along with a 2% improvement in supply chain automation from 2006 to 2026, will lead to an average increase of 0.73% in the flexibility of the smart supply chain in the health industry during the specified period (Figure 12).



Year	2023	2024	2025	2026
Basic values	0.4293	0.4261	0.4229	0.4195
Scenario 4	0.4383	0.4351	0.4317	0.4282

Figure 12. Prediction of a 5% upgrade of smart communication and smart warehouse and a 2% upgrade of supply chain automation and its effect on the flexibility of the smart supply chain

5. Discussion

To model the smart supply chain in the health sector using the system dynamics approach, the first step involved defining and setting the boundaries of the model after identifying the influential variables. Subsequently, submodels and the final research model were developed by identifying the causal relationships between these variables.

It is worth mentioning that this research focused on identifying the gap between the current and desired situations. Possible scenarios were then implemented to enhance the flexibility of the smart supply chain in the country's health industry. Based on the research findings, improvements in the state of smart warehouses or smart communication during the study period corresponded to an expected increase in the flexibility of the supply chain by 2.08% and 1.4%, respectively. However, simultaneous changes in both of these aspects not only failed to enhance the flexibility of the smart supply chain but also had the potential to reduce flexibility. This is primarily due to the potential disruptions and rework introduced by changes made to traditional systems, which can hinder the smooth functioning of the supply chain.

The research model presented four scenarios to improve the supply chain's flexibility. The best-performing scenarios were the improvement of the smart warehouse condition, enhancement of smart communication, simultaneous implementation of both changes, and upgrading the administrative automation of the supply chain. Policymakers are advised to focus on implementing changes in either the smart warehouse or smart communication variable to create an environment conducive to improving the flexibility of the health industry's supply chain.

Furthermore, it is recommended that future researchers expand the model boundaries and explore the causal relationships among newly identified variables to enhance and refine the model. This would provide a more accurate prediction of the flexibility level in the smart supply chain within the country's health industry.

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Footnotes

Conflict of interest:

There is no conflict of interest.

Funding/Support:

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