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A System Dynamics Approach for Value Chain Analysis in the Pharmaceutical Industry

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Abstract

Given the importance of increasing value in various industries, the continuous improvement of value chains has always been one of the main priorities of governments. This issue is particularly significant in key industries, especially the pharmaceutical industry, which, by ensuring public health, leads to improved quality of life. This study aims to investigate the factors influencing value chain (VC) in Iran pharmaceutical industry. For this purpose, pharmaceutical VC experts in the Sobahan Darou company were interviewed. Next, systems dynamics is used to simulate the dynamics of the pharmaceutical VC. So, the interactions of the main variables were translated to the dynamic hypotheses and constitute the causal loop diagram. Then, stock and flow diagram was formulated in form of the differential equations. To validate the proposed model, some structural and behavioral validation test were examined which indicated model's accuracy. Finally, four potential scenarios were developed based on the company's facilities and increase in marketing and sales costs, investment in skilled human resources and investment in research and development, and the effect of these scenarios on four basic variables, namely customer satisfaction, financial strength, polution and VC efficiency were investigated. Based on the results, the fourth scenario has the heghest effect on customer satisfaction and emission reduction. While the second scenario led to highest increase on VC efficiency and financial strength.

Keywords: Value Chain, Profitability, Technology, System Dynamics

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1-Introduction

Global competition increasingly rised and value chains are facing rapid changes in customer demand, reduced response times, and improvements in production technology. In such an environment, companies are less inclined to compete independently and are instead part of a larger value chain and competitive landscape. The connections between organizations through value chains imply that one organization utilizes the output of another to create a more complex product (Khorana et al., 2022). Value chains generate numerous opportunities for organizations from developing and emerging economies by allowing firms to participate without needing to manage every stage of complex production processes (OECD, 2021). Furthermore, various elements within the value chain share their knowledge and skills to create greater value for their customers. To achieve a sustainable competitive advantage in a highly competitive market, an efficient value chain is essential (Srikar et al., 2022).

Currently, more than two-thirds of global trade takes place within value chains (Khorana et al., 2022). Consequently, major companies are constantly seeking over 70% of global trade solutions to enhance the efficiency of their value chains. These solutions can also be used for continuous business improvement and future strategic planning (Strange & Zucchella, 2017 , Nozari & Nahr, 2022). Given that value chains are influenced by many factors and are complex systems with high interactions, understanding the actions required to achieve desirable outcomes is challenging and poses difficulties. Despite the variety of approaches used to analyze value chain elements, the nature of interactions among these elements remains a fundamental challenge (Hainzer et al., 2019). This challenge has become more pronounced in the past decade due to the increasing complexity of value chains and the growing importance of corporate social responsibility in the design and management of these chains. Theoretical frameworks have studied such changes in terms of institutional and macroeconomic factors, including increased protectionism (Juergensen et al., 2020), sustainability (Pananond et al., 2020), technological advancements (Hannibal & Knight, 2018), big data (Strange & Zucchella, 2018), disruptive low-probability but high-impact events, high-quality inputs, quality labels, learning through internal/external training, and regulatory frameworks (Srikar et al., 2022). Moreover, factors such as time, the role of non-organizational actors, their interactions, and decisions that contribute to creating a stronger value chain have been less studied, making it more challenging to compare and identify common factors affecting value chain development (Villalba et al., 2023).

Deciding how to improve the pharmaceutical value chain is a complex issue that, if addressed successfully, can ensure the growth and profitability of pharmaceutical companies and the health of the community. The Biotechnology Development Headquarters of the Presidential Office of Science and Technology has established national and comprehensive programs to enhance the health sector in the country. These programs include the production of raw materials for medicine manufacturing, medicine production, human vaccine production, production of cosmetic and personal care products, natural, traditional, and supplementary products, medical equipment and supplies, and completing the value chain for industrial pharmaceutical materials. Complete implementation of these programs is expected to add $6.774 billion to the national gross income (Siyadat et al., 2022). According to the Presidential Office of Science and Technology, 64 national programs have been defined to complete the value chain for industrial pharmaceutical materials. With the help of these programs and the expertise of knowledge-based companies, the necessary industrial materials for medicine production can be provided. If resources are secured, $1.1 billion in added value will be injected into the country's economy within the next five years (Farsnews, 2021).

Pharmaceutical production in Iran during the period from 2012 to 2021 has experienced significant growth despite challenges such as economic sanctions and currency fluctuations. According to statistics published by the Ministry of Health, about 60% of the Iran’s required medications were imported in 2012, but by 2021, this figure had decreased to around 30% (Tavakkol et al., 2023a; Tavakkol et al., 2023b). Overally, pharmaceutical production during this period experienced remarkable growth. According to published statistics, the volume of pharmaceutical production in Iran was approximately 70,000 tons in 2012, which increased to over 120,000 tons by 2021. Additionally, the number of pharmaceutical manufacturing companies also saw a significant increase during this period (See Figure 1).

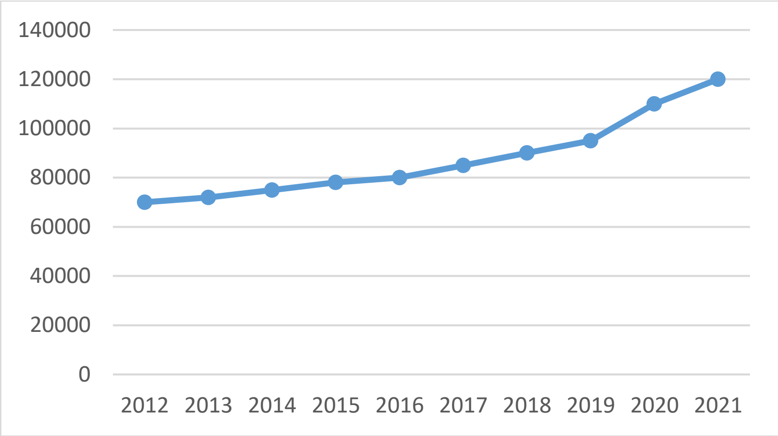

Figure 1. Reference Mode for Medicine Production (Tone)

Given the importance and role of the pharmaceutical industry in environmental preservation, health, and economic growth, this research focuses on this sector. The study aims to analyse the dynamics of pharmaceutical value chain and provide a comprehensive insight into the affecting factors through a conceptual model. This model is intended to help the government, raw material suppliers, market regulators, and other stakeholders gain a better understanding of pharmaceutical value chains and their operations. This understanding can lead to better policies and regulations, as well as more efficient and cost-effective services for patients.

2-Literature Review

Value chain analysis enables companies to distinguish themselves from competitors by identifying sources of competitive advantage. Essentially, the value chain is a fundamental tool for recognizing competitive advantages and finding ways to create and sustain them (Lambert & Cooper, 2000). By understanding the points at which value is added throughout the chain, companies can leverage their unique capabilities and resources to enhance their market position. To achieve effectiveness, stakeholders within the value chain must continuously collaborate to optimize the flow of goods, information, and finances (Villalba et al., 2023). Value chains have created new opportunities for many organizations and developing economies, as participation in these chains means companies are not required to master all stages of complex production processes (OECD, 2021). The reconfiguration of inter-company relationships, while improving operational efficiency, can also increase vulnerability to systemic shocks (Khorana et al., 2022; Kokkinos et al., 2022).

One of the most important tools for value chain analysis is Porter's value chain model. Porter described the activities a company undertakes from raw material procurement to the final delivery of the product to the end consumer as a chain, where value is added to goods or services at each stage (Kharaghani et al., 2024). This model provides an overview of business activities, dividing them into primary and support activities (Figure 2). Primary activities pertain to the production of a product and its delivery to the customer, while support activities facilitate the primary activities. According to Porter (1985), primary and support activities are not only interconnected but also interact with the value chains of external stakeholders, such as suppliers, channels, and customers, representing a source of competitive advantage.

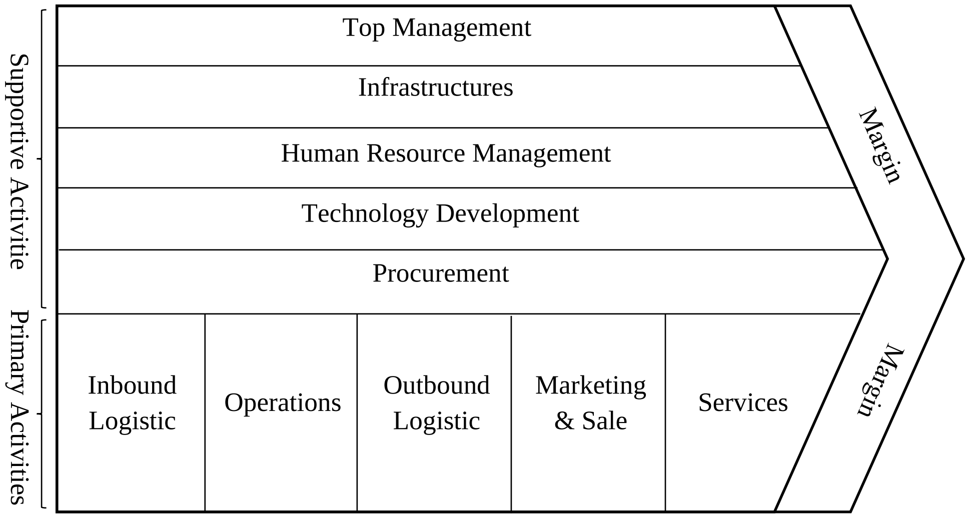

Figure 2. Overview of Porter's Value Chain (Porter, 1985)

Porter's framework consists of primary activities (such as inbound logistics, operations, outbound logistics, marketing and sales, and after-sales services) and support activities (including senior management, infrastructure, technology development, human resource management, and procurement), all of which contribute to product value creation. Following Porter, various studies on the concept of value chains have led to different approaches for value chain analysis (Lambeert & Cooper, 2000). For example, Villalba et al. (2023) analyzed the role of banks, development organizations, agricultural businesses, and universities in identifying drivers of financial development in agricultural value chains through in-depth expert interviews. They proposed a framework for creating long-term financial development plans for agricultural value chains in developing countries, including establishing financial platforms for value chain transactions, implementing immediate services for the value chain, and evolving from a value chain approach to a web value approach.

Low et al. (2023) reviewed the literature of the food value chain with a focus on food value chain concepts, using thematic analysis to code evidence and categorize these codes into four main areas: value creation, the impact of the agricultural environment on value creation, ecosystem service evaluation, and the integration of supply chains and value chains. Sengupta and Dreyer (2023) explored the concept of a waste-free value chain, examining how digital sales and operational planning can serve as components for forecasting and identifying changes across the value chain, as well as reallocating surplus food. Eisenreich et al. (2022) structured potential circular economy concepts within Porter's value chain framework and identified seven main themes. The analyses indicate that the linear structure of Porter's model is insufficient for reflecting circular business practices. Khorana et al. (2022) simulated scenarios to examine the participation of Commonwealth countries in global value chains post-COVID, revealing that trade support is likely to impact supply chains and lead to a reconfiguration of global value chains. Ayele et al. (2022) analyzed the wheat value chain in the Dona and Hadiya regions of southern Ethiopia. The results of a multivariate linear regression model showed that wheat supply is influenced by factors such as the amount of wheat produced, household education level, farming experience, frequency of extension contacts, and lagged market prices. Additionally, wheat producers identified climate change and low wheat prices as two primary issues affecting wheat production and marketing.

By examining the studies conducted on VC in the supply chain, a list of affecting factors is summarized in Table (1):

Table 1. The affecting factors on value chain

Category	Factors
Institutional	Value chain resilience

Category	Factors
Infrastructures	Financial strength
	Recycling capabilities
HRM	Skilled human resources
Technology Development	Production technology
	Research and Development
Operations	Operational efficiency
	Non-value-adding activities
Outbound Logistics	Transportation/Distribution cost
Marketing & Sale	Medicine price
Industry Forces	VC governance
Political Factors	Import limitations
Economic Factors	Cost of raw materials
	Cost of energy
Social Factors	Consumer behavior and social trends
Technological Factors	Technological capabilities
	Internet of Things
Legal Factors	Government policies
Environmental Factors	Sustainable waste management
	Environmental concerns about waste disposal

A systematic review of value chain studies reveals that most of the researches have been based on non-exploratory tools and typically address the value chain from a narrow perspective. These studies aim to elucidate the concept of the value chain and facilitate its understanding and implementation for stakeholders. However, the applied methods have not adopted a comprehensive approach to systematically categorize the factors influencing the value chain and examine their interactions. The use of system dynamics in this research will help researchers to address the problem and contribute to the VC policy-making process.

3-Results

In this section, system dynamics is used as the analytical tool to examine the behavior of the value chain variables. Research experts include 14 experts of Sobahan Darou Company in Iran which selected based on their theoretical knowledge, practical experience and willingness to participate in the research. The data was collected by interview and questionnaire, and analysed using Vensim PLE 6.1 software. The cause-and-effect loops focus on the main elements of the model: the pharmaceutical manufacturer, raw material supplier, distributor, and pharmacy, which will be illustrated further. Sobhan Darou is considered for simulating the model, in a six-month time horizon is used in the equations for the four proposed scenarios. In some sections, lookup functions are used due to the lack of real data. Finally, model's validation is tested using common system dynamics validation tests.

3-1-Cause-and-Effect Diagrams (CDLs)

- *CLD of Manufacturer Profitability*

The cause-and-effect loop related to the profitability of a pharmaceutical manufacturer is illustrated below. As shown in Figure (3), an increase in the demand for medicines leads to an increase in medicine production by the manufacturer and an increase in the medicine stock in the company's inventory. actually, selling more medicines to customers results in increased revenue and profitability for the pharmaceutical manufacturer. It is expected that with increased profitability, the company's financial strength will improve, leading to more investment in research and development. This will have a direct impact on medicine quality and the promution of the company's brand, which is one of the most significant outcomes, resulting in increased customer demand.

On the other hand, an increase in medicine demand leads to an increase in medicine production by and an increase in the medicine stock in the company's inventory. Then, selling more medicines to customers results in increased revenue and profitability for the manufacturer. As profitability increases, the company's financial strength improves, allowing for increased spending in various areas such as marketing. As marketing activities increase, the number of customers for the company's products grows, leading to higher medicine demand.
In another part of the Figure (3), increased medicine quality results in higher customer satisfaction and, consequently, increased sales for the company. Selling more medicines to customers results in increased revenue and profitability for manufacturer. It is expected that with increased profitability, the company's financial strength will improve, leading to greater investment in research and development. This will result in increased innovation in production and increase in medicine quality.
Finally, as illustrated in Figure (3), increase in medicine production by the manufacturer and selling more medicines to customers result in increased revenue and greater profitability. It is expected that with increase in profitability, the company's financial strength will improve, allowing for higher spending in the logistics department, which facilitates and increases the production capacity of the manufacturer.

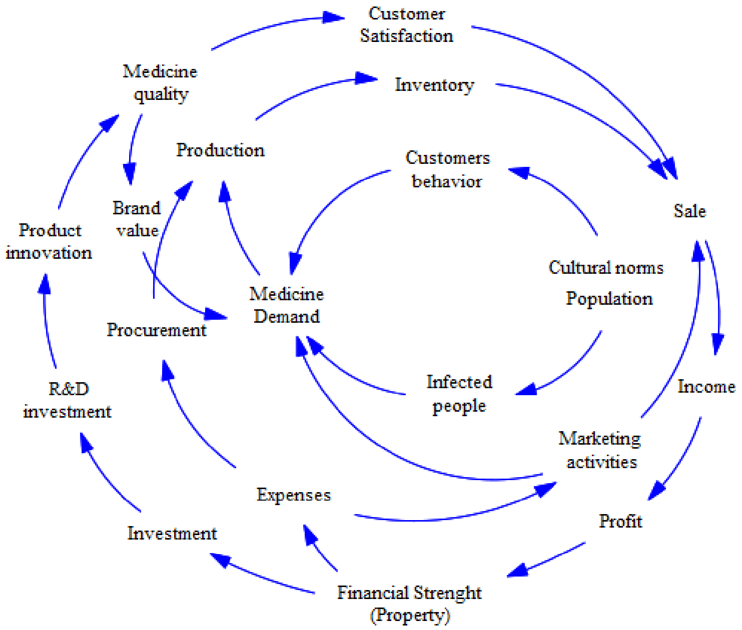

Figure 3. CLD of Manufacturer's Profitability

- *CLD of Green Production*

The following diagram illustrates the cause-and-effect for green production of pharmaceutical products. As shown in Figure (4), this part of the cause-and-effect model, like the previous section, contains multiple loops. The production of waste and pollutants, as well as gas emission, leads to an increase in environmental pollution. This, results in the enactment of more environmental regulations, which force manufacturers to adopt green sourcing practices. This change affects both the production and packaging processes, leading to the use of recyclable materials that can be returned into the production cycle. The use of these materials improves green production practices and reduces waste and pollution.
On the other hand, the increase in pollution caused by the waste production, pollutants, and green house gases leads to stricter environmental regulations, which obligates manufacturers to establish green production systems. This can be observed in areas such as employee training, energy-efficient technologies, and waste reduction.

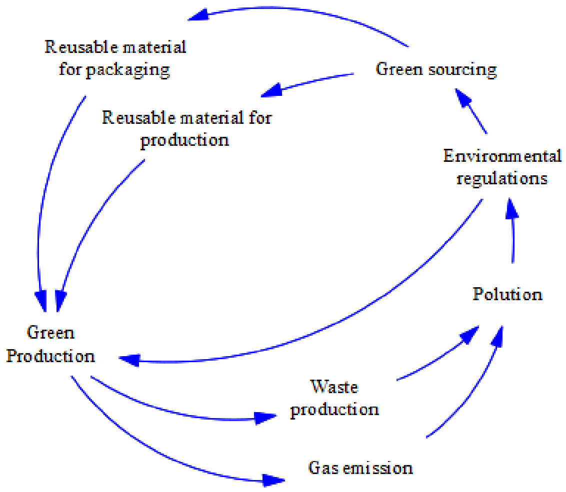

Figure 4. CLD of Manufacturer's Profitability

- *CLD of Brand Value*

The following diagram illustrates the cause-and-effect loops related to the brand of medicine manufacturers. As illustrated in Figure (5), an increase in the manufacturer's reputation leads to an increase in its brand value. Reputation of the manufacturer encourages both domestic and international manufacturers to grant various licenses and certificates to the medicine manufacturer. Consequently, the company gains the ability to produce more medicines, or in other words, the diversity of the company's product range increases. It is expected that this product diversity will further enhance the company's brand reputation.

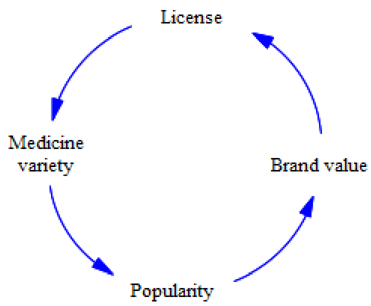

Figure 5. CLD of Manufacturer's Brand Value

- *CLD of Manufacturer Efficiency*

This section examines the cause-and-effect loops related to the manufacturer efficiency. Reduction in production costs leads to greater profitability for the manufacturer, which subsequently increases its financial strength. This enables greater investment in the company's information and communication infrastructure, such as the adoption of Industry 4.0 technology. One of the most significant outcomes of this practices is the implementation of the Internet of Things (IoT) in various organizational processes. This development improves product quality control and monitoring as well as the value chain integration, which in turn leads to increase in value chain efficiency. More efficiency in the manufacturer's value chain will result in lower production costs. This dynamic hypothesis illustrated in Figure (6).

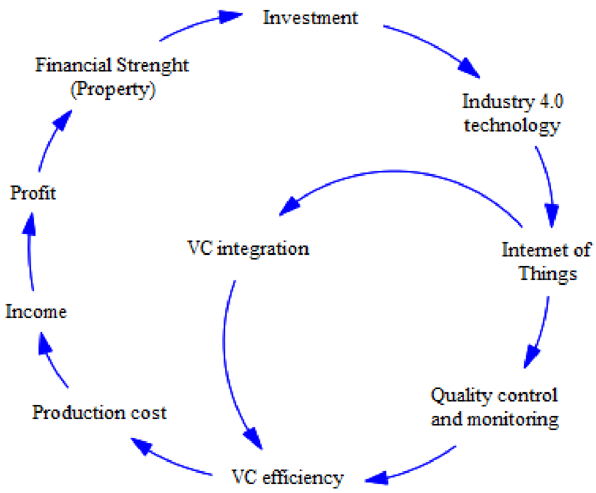

Figure 6. CLD of Value Chain Efficiency

3-2-Stock and Flow Diagram of the Value Chain

Based on the cause-and-effect diagrams presented in Figures (3) to (6), the cause-and-effect diagram of the research is depicted. To draw the flow-stock diagram of the pharmaceutical production value chain, it is necessary to categorize these variables into constant, auxiliary, stock and flow variables. Accordingly, the final research model consists of 2 stock variables, 5 flow variables, 72 auxiliary variables (including intermediate variables and table functions), and 12 constants.

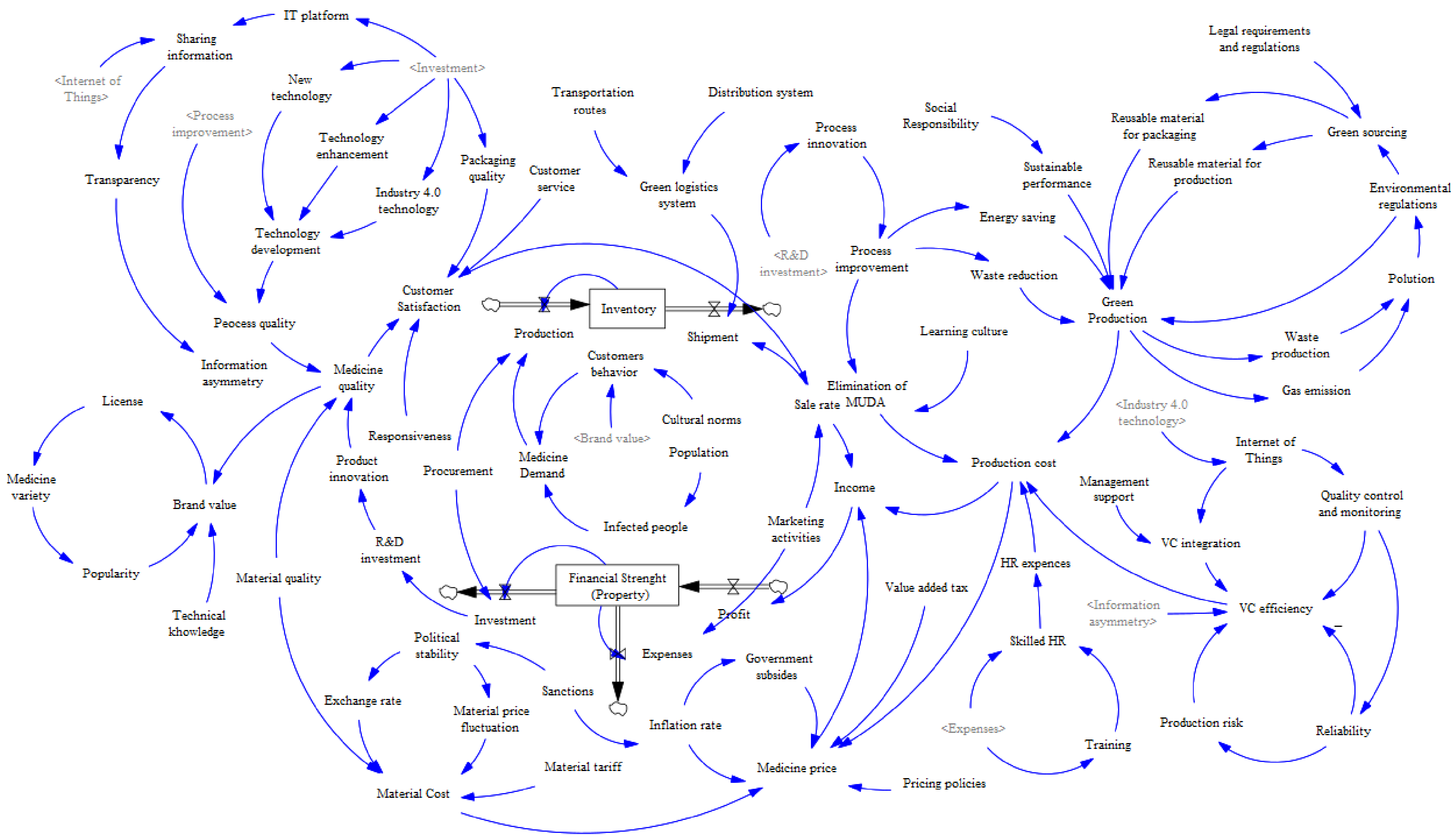

Figure 7. Stock & Flow diagram of the pharmaceutical value chain

3-3-Validity Tests

Based on the implementation of the structural (boundary adequacy test and dimension consistency test) and behavioral (integration error test, behavior reproduction test, and sensitivity analysis test) validity tests, the model has been validated.

To conduct the boundary adequacy test, the opinions of two experts with experience as technical managers at Sobhan Darou company were utilized. They reviewed and confirmed the cause and effect structure of the model and the its behavior. For the dimension consistency test, the accuracy of the units for various variables was also reviewed in the stock and flow diagram. Based on the results, both "Units are OK" and "Model is OK" messages were appeared.

According to the results of integration error test, the behavior of the main variables was similar and the integration error was negligible. In the behavior reproduction test, the behavior produced by the simulation of the main variables was compared with their reference behavior. Given the high similarity in the trends of the variables, the behavioral validity of the model was confirmed. The RMSPE (Root Mean Square Percentage Error) value for the main variables of the research model was also less than 0.1.

- *Sensitivity Analysis of the Model*

Sensitivity analysis involves studying the behavior of target variables because of the changes in input variables within a mathematical model. In other words, it is a method for systematically manipulate the inputs variables to predict how these changes affect the model's variables. To evaluate sensitivity analysis in Vensim PLE software, several key exogenous variables in the stock and flow diagrams were selected, and their effects on another target variable in the same model were assessed for two different values. The change in the behavior of the target variable indicates the model's sensitivity to the values of the exogenous variables. So, SyntheSim sensitivity analysis was used to evaluate the behavior of the model's key variables. For example, if the price of a medicine significantly falls, the model should show a higher level of customer satisfaction and reflect its impact on demand. Therefore, if the price of the product decreases from 2000 units to 1000 units at time 10, the percentage of customer satisfaction will increase by 0.5 units. The pattern of this change is shown in Figure (8).

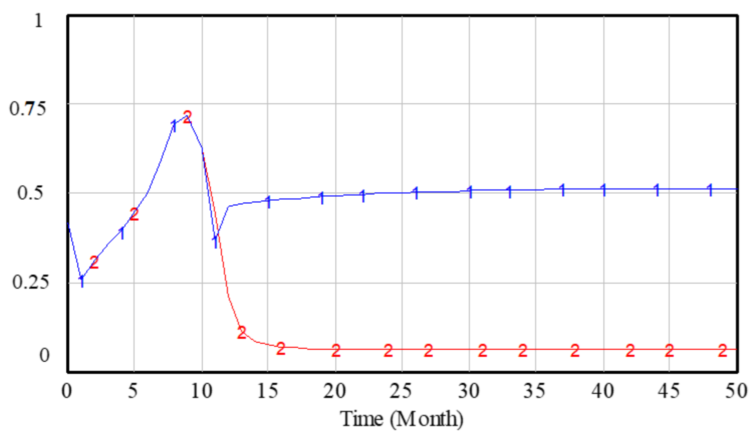

Figure 8. Sensitivity analysis of Customer Satisfaction

Additionally, with the dicrease in medicine price to 1500 units at time 10, the model experiences an increase in medicine demand, as shown in Figure (9). Note that the baseline is indicated in red.

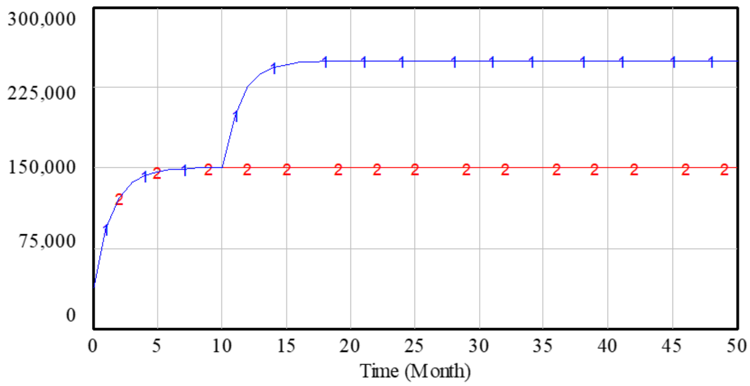

Figure 9. Sensitivity analysis of Customer Demand

4-Discussion

In the present study, four scenarios have been considered based on the policies and capabilities of the company's value chain. It is important to note that the scenarios related to marketing and sales expenses, investment in skilled human resources, and investment in research and development have been selected as the determining factors for these scenarios due to their essential roles in the value chain and the availability of related data. As shown in Table (2), in the baseline scenario, the marketing and sales expenses, investment in skilled human resources, and investment in research and development are set equal to the values defined in the simulated model. It is assumed that the company has achieved a specific profit denoted by "a" and intends to invest a portion of it in marketing and sales, skilled human resources, and research and development. Obviously, various combinations for this investment could be proposed, which can be defined as percentages investment in each sector. Table (2) illustrates the different scenarios for value chain improvement.

Table 2. Research Scenarios

Scenario	R&D Investment	HR Investment	Marketing & Sale Expenses
Base line	-	-	-
Scenario 2	2% Increase	5% Increase	30% Increase
Scenario 3	5% Increase	3% Increase	20% Increase
Scenario 4	8% Increase	2% Increase	10% Increase

In this study, marketing & sales expenses, investment in skilled human resources, and investment in research and development have been considered as main variables for scenario development. Sobhan Darou Co. intends to invest some budget in three areas: (1) marketing and sale, (2) recruitment the skilled human resources, and (3) research and development. Given the budget constraints, various combinations for allocating this budget and the impact of the allocation method on the key variables can be defined. In all figures, in addition to the baseline scenario (implementing the model without changes), three other scenarios are proposed based on the percentage of budget allocated to the three investment areas.

Note that the same percentage increase in budget across two areas does not imply an equal amount of investment. This is because the percentage is calculated based on the increase in budget relative to the total investment made in each respective area. To clarify, let's assume the initial investments in areas A and B are 2000 and 5000 units, respectively. If we plan to invest 1000 additional units in these two areas and allocate 500 units to A and 500 units to B, this would actually result in 25% increase in A and 10% increase in B. Therefore, an equal percentage increase in investment does not equate to an equal budget allocation.

Based on the explanations, implementation of the company's policies within the framework of Scenarios 2 to 4 from Table (2) will be evaluated concerning four key variables of the value chain system: customer satisfaction, financial strength, environmental concerns (pollution), and value chain efficiency.

- *Customer Satisfaction*

Customer satisfaction is one of the most significant variables affecting value chain. As shown in Figure (10), the impact of each scenario on the customer satisfaction variable has been examined. Among the four scenarios, Scenario 4—where there is a 10% increase in marketing and sales expenses, a 2% increase in investment in skilled human resources, and a 8% increase in investment in research and development—cause to the highest customer satisfaction (approximately 85%) over the time horizon considered. Scenarios 3, 2, and the base scenario follow in descending order.

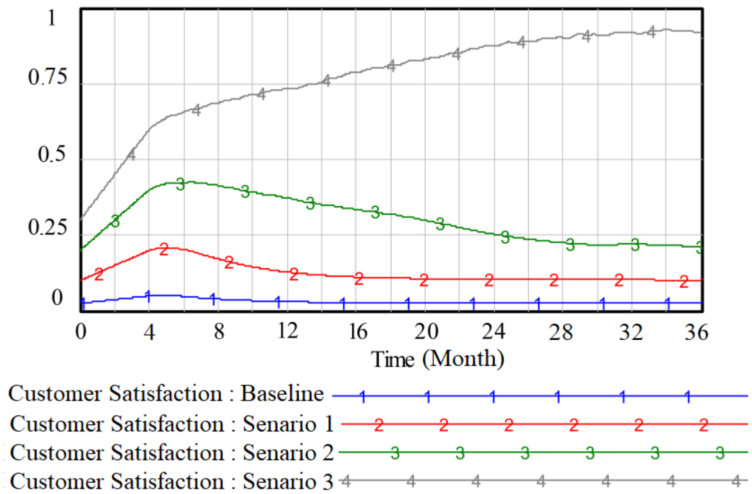

Figure 10. Effect of Scenario Implementation on Customer Satisfaction

- *Pollution*

From an environmental perspective, pollution is recognized as one of the most critical variables in the value chain. In Figure (11), the effect of four scenarios on the pollution variable has been illustrated. Among the four scenarios, Scenario 4—which includes a 10% increase in marketing and sale expenses, a 2% increase in investment in skilled human resources, and a 8% increase in investment in research and development—cause to the highest pollution reduction over the time horizon. Scenarios 3, 2, and the baseline scenario follow in descending order.

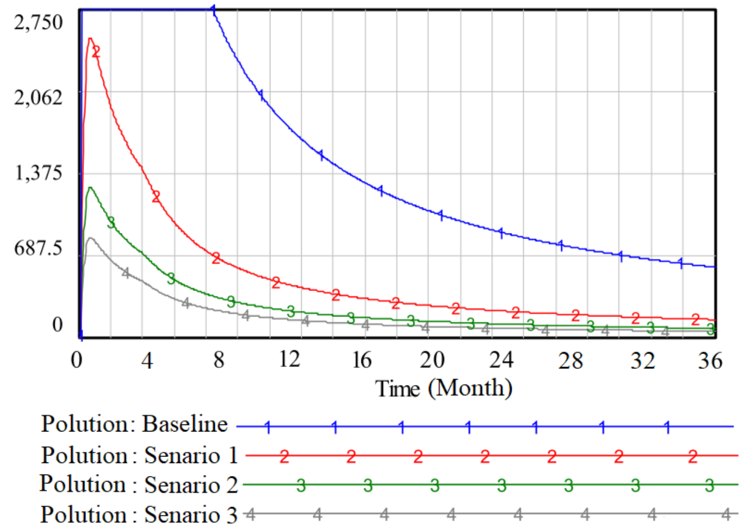

Figure 11. Examining the Effect of Scenario Implementation on Pollution

- *Value Chain Efficiency*

Efficiency is another crucial variable influencing the value chain. The effect of implementing each scenario on the value chain efficiency illustrated in Figure (12). Among the four scenarios, Scenario 2—which includes a 30% increase in marketing and sale expenses, 5% increase in investment in skilled human resources, and 2% increase in investment in research and development—leads to the highest improvement in value chain efficiency over the time horizon. Scenarios 3, 4, and the baseline scenario follow in descending order.

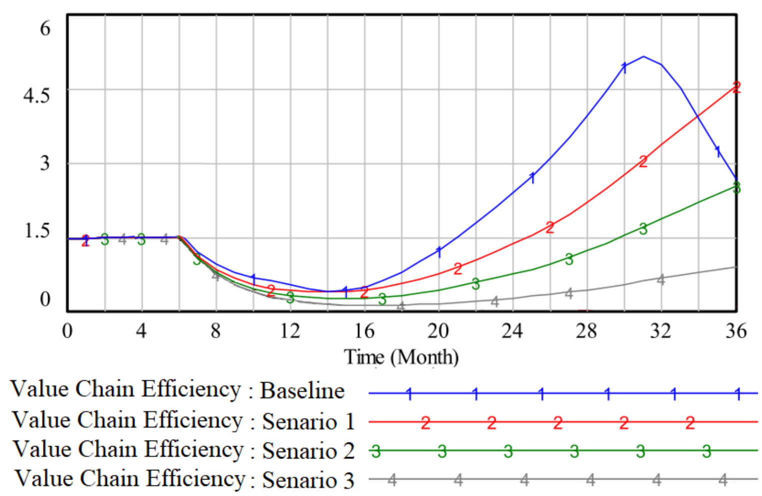

Figure 12. Effect of Scenario Implementation on Value Chain Efficiency

- *Financial Strength*

Financial strength is another key variable affecting the value chain. As illustrated in Figure (13), the effect of developing 4 scenario on the financial strength has been examined. Among the four scenarios, Scenario 2—which involves a 30% increase in marketing and sale expenses, 5% increase in investment in skilled human resources, and a 2% increase in investment in research and development—results in the highest improvement in financial strength over the time horizon. Scenarios 4, 3, and the baseline scenario are in the next order, respectively.

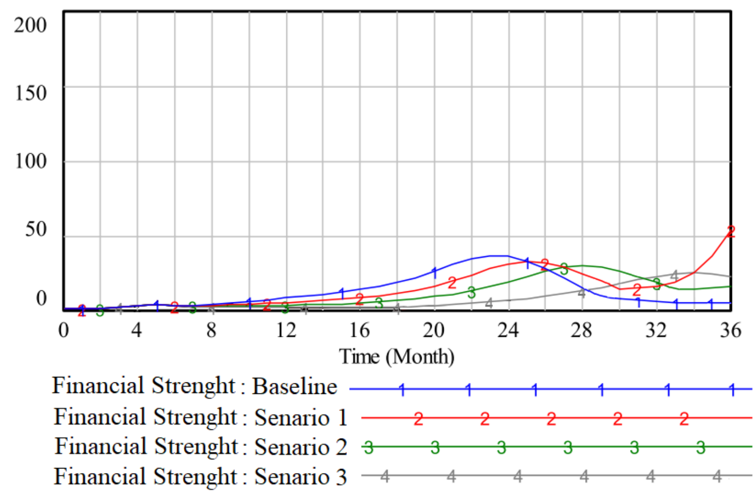

Figure 13. Effect of Scenario Implementation on Financial Strength

The implementation of the company's policies within the framework of the defined scenarios was examined across four key variables of the value chain system: customer satisfaction, financial strength, environmental concerns (pollution), and value chain efficiency. Among the four scenarios, scenario 4—achieves the highest customer satisfaction, while scenarios 3, 2, and the baseline scenario were ranked 2nd to 4th. Scenario 4 also results in the greatest reduction in pollution over the simulation time horizon. Scenarios 3, 2, and the baseline scenario are ranked next in terms of pollution reduction.

Among the four scenarios, scenario 2 provides the highest improvement in value chain efficiency over the simulation time horizon. Scenarios 3, 4, and the baseline scenario are ranked in descending order. Finally, scenario 2 results in the highest increase in financial strength, with scenarios 4, 3, and the baseline scenario in the next orders.

5-Conclusions

Successful policies for value chain success are always associated with two fundamental characteristics: integration and coordination of the value chain players. Value creation requires alignment of various business attributes within an integrated system. In this research, factors affecting the value chain are categorized into institutional factors, factors related to the company's value chain, industry factors, and factors arising from the political, economic, social, technological, legal, and environmental environment. Given the importance of these factors, examining and leveraging the benefits of collaboration with business partners throughout the pharmaceutical industry value chain can bring significant improvements. Reassessing and optimizing production, raw material procurement, distribution, and sales processes can help reduce costs and enhance speed and quality within the pharmaceutical industry value chain. Utilizing modern technologies such as artificial intelligence, cloud computing, and the Internet of Things can lead to significant improvements in transparency and efficiency in the pharmaceutical value chain. Attention to environmental issues and engagement with local communities, improving access to medicines, and social responsibility can strengthen the pharmaceutical industry value chain. Meanwhile, investment in employee training and development for increased productivity and enhancement of quality and competitive strength can provide substantial added value. Revising the industry structure and creating balance among the players in the supply chain and market forces are priorities that decision-makers should address to ensure that all companies in the pharmaceutical industry can access diverse resources and markets, thereby benefiting from profitability and growth opportunities. Facilitating mechanisms for building trust, coordination, and

collaboration among the supply chain elements to establish sustainable relationships is another key recommendation of this research.
Political efforts by the government to improve international relations and lifting sanctions, which contribute to political stability and a clear outlook in inter-regional interactions, are also crucial from a political perspective for the pharmaceutical industry. From the inter-organizational perspective, it is recommended that pharmaceutical companies enhance the learning culture throughout the organization by training and developing human resources. Implementing proper work training programs and developing new competencies can leverage the advantages of skilled, multi-talented, and knowledge-creating human resources, who have the capability to generate and enhance value. Based on the findings, it is recommended that senior managers in the pharmaceutical industry focus on leveraging technological capabilities, government policies, and financial strength when formulating their strategies.
This research faced several limitations, including the following: It was conducted without accounting for the perishability and specific expiration dates of certain medicines. Additionally, precise and actual figures for Subhan Darou were not always available, necessitating the use of lookup functions in the system simulation alongside expert opinions. For future research, it is recommended to consider pharmaceuticals as perishable products in modeling and to focus specifically on certain categories of medicines. Furthermore, it is suggested to examine various scenarios in modeling based on changes in other parameters.

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