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Optimizing Supply Chain Performance: A System Dynamics Approach Emphasizing Agility and Flexibility

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Abstract- This research aims to enhance supply chain performance by developing a system dynamics model, emphasizing agility and flexibility indicators. The increasing complexity of goods and services has presented individual companies with survival challenges in the absence of support and collaboration from other organizations. Recognizing the potential benefits of cooperation, organizations have acknowledged that collective efforts yield superior outcomes compared to isolated activities. The modeling approach seeks to reduce costs, lead times, and enhance customer satisfaction while considering agility and flexibility factors. Through literature reviews and expert interviews, essential concepts and indicators were evaluated, leading to the determination of cause and effect relationships between variables and the construction of the model. The results revealed that neither agility nor flexibility alone can ensure profitability; instead, an optimal balance of both is crucial to maximize profitability. Consequently, an optimal level of agility and flexibility has been estimated to guide effective decision-making and improve overall supply chain performance.
Keywords- System dynamics model; Decision-making; Supply chain performance; Complexity; Agility.

1. Introduction

The intensifying global competition, the rapid introduction of new products with short market lifecycles, and heightened customer expectations have necessitated substantial investment and strategic focus on supply chains by businesses. In the current business landscape, competition extends beyond individual companies to encompass entire supply chains. As a result, supply chain management has emerged as a crucial strategic tool for companies to effectively handle quality management, ensure customer satisfaction, and sustain competitiveness.

A method of effectively orchestrating timely and accurate responses to systemic challenges involves documenting and analyzing pivotal functional aspects of the system's future scenario, which incorporates its past and present behaviors. Achieving this objective demands the application of knowledge and a systemic approach to identify problems accurately and determine the swiftest and most appropriate resolution. This domain of knowledge is known as "system dynamics." [1]

Trust-building between different stages of the supply chain, information exchange concerning market requirements, and the development of customer-oriented products constitute the core objectives of supply chain management. Additionally, fostering long-term relationships among the various stages of the chain is a central focus [2, 3]. The concept of "supply chain management" encompasses a broad scope, involving component suppliers, major suppliers, internal operations, major customers, component customers, and end consumers, with the primary aim of satisfying the ultimate customers within the purview of supply chain management [4, 5]. Supply is a concept originating from the manufacturing industries, with its earliest indications of supply chain management emerging in Toyota's "JIT" (Just-In-Time) production system [6, 7]. This system is designed to minimize inventory levels and regulate interactions between suppliers and the production line department, effectively creating an efficient approach. Subsequently, with the introduction of the supply chain management approach in the Japanese automobile industry, it evolved from being a subset of the production system to a distinct and prominent concept within the domain of industrial management theory. This transformation marked the proposal of supply chain management as an independent and fundamental concept in the theory of industrial management.

In practice, supply chain management comprises a fusion of specialized domains within the conceptual space of management, encompassing comprehensive quality management, the business redesign process, and accurate and timely production methods. Consequently, the supply chain can be conceptualized as an interconnected network of companies involved in the procurement of raw materials, the transformation of these materials into semi-finished and finished products, and the distribution of the final product to end customers [8].

This research endeavors to enhance supply chain performance through the development of a system dynamics model that places a significant emphasis on agility and flexibility indicators. The primary objective is to reduce costs, improve efficiency in terms of time, and elevate the level of customer satisfaction by comprehensively considering the indicators of agility and flexibility.

To achieve this aim, this study employs various scenarios to model the factors influencing agility and flexibility within the supply chain using a cause and effect approach. Initially, essential concepts will be introduced, followed by a thorough review of existing literature and expert interviews to identify the pertinent indicators of agility and flexibility, as well as the key objectives of the field. Within the initial stage, influential indicators from prior studies, such as responsiveness level, customer needs, market sensitivity, immediate adaptability to changes, sourcing flexibility, distribution flexibility, and production flexibility, will be examined, with a subsequent analysis of their impact on time, costs, and customer satisfaction.

Based on the outcomes of this analysis, state variables (time, cost, customer satisfaction) will be defined to model the system dynamics, leading to the formulation of various strategies and scenarios. Consequently, an operational plan for the obtained scenarios will be designed and structured within different time horizons, allowing for comprehensive evaluations and optimal decision-making to enhance the overall performance of the supply chain.

2. Literature review

The concepts of agility and flexibility in the supply chain are subject to review in the article. A structured review method was employed, leading to the identification of 83 relevant review articles, achieved through a meticulous three-step refining process. The search encompassed data reduction techniques utilizing programming, string and keyword review of the article's title, abstract, and conclusion. The reviewed literature primarily focuses on organizational agility and flexibility within the supply chain domain. Within this context, recognized gaps in understanding and developing agility and flexibility in supply chains were identified and subsequently categorized into conceptual, textual, and methodological gaps. Upon thorough analysis of these identified gaps, this paper posits that establishing effective relationships with key partners constitutes a crucial mechanism to mitigate the challenge of losing control. This obstacle hinders academic comprehension and impedes the development and application of agile and flexible capabilities within supply chains.

Chan et al. [5] employ a resource-based perspective to explore the antecedents and consequences of supply chain agility, emphasizing both strategic and operational dimensions. They argue that strategic flexibility and production flexibility are crucial for establishing supply chain agility, which in turn affects company performance. Through an empirical investigation involving industry experts and structural equation modeling, the study confirms the significant influence of both strategic and production flexibility on supply chain agility, based on analysis of data from 141 apparel manufacturers.

Kim and Chai [6] conducted a study investigating the influence of supplier innovation on supply chain collaboration and agility. The research employs the diffusion of innovation theory to elucidate the distribution of supplier innovation within the supply chain and examines how global sourcing moderates the associations among supplier innovation, information sharing, strategic resources, and supply chain agility. The study gathered survey responses from 272 managers, production, and purchasing managers in the manufacturing industry. The findings of the research reveal that supplier innovation positively impacts information sharing and supply chain agility, although it does not demonstrate a significant relationship with strategic resources.

Rojo et al.'s [7] research aims to investigate and assess the relationship between environmental dynamism and supply chain flexibility (SCF). Additionally, the study explores the necessity of two dynamic capabilities, namely operational absorptive capacity (OAC) and organizational learning (OL), for firm development. The hypothesized relationships were empirically tested using survey data gathered from 302 Spanish manufacturing companies, employing structural equation modeling as the analytical approach. The findings indicate a positive correlation between environmental dynamism and both OAC and OL, with both dynamic capabilities contributing to the dynamism of SCF. Moreover, the authors identify that the association between environmental dynamism and SCF is mediated by OAC and OL. The research makes significant contributions to the literature, notably in determining the advantageous factors conducive to SCF development and specifying the essential capabilities firms require to effectively align SCF with the environmental context. As a practical implication, managers are encouraged to prioritize the development of SCF through the cultivation of OAC and OL when confronted with heightened environmental dynamism.

In the research conducted by Hendalianpour et al. [8], the agile and flexible allocation of orders to suppliers is explored, particularly in the context of the automotive industry. The study involves the removal of parts sourced from a single supplier from the parts collection. Through a combination of mathematical modeling, stable ideal planning, and IVFRN-BWM (Interval-valued Fuzzy Robust Network-Based Weighted Method), the authors aim to achieve results that cater to the needs of the proposed model, offering optimal outcomes through the introduction of new modes. The article addresses novel aspects of the subject matter and achieves robust results by considering five goal functions: Minimizing production line disruptions due to supplier performance, Minimizing production line complaints about supplied parts, Minimizing Defective Parts Per Million (PPM), Maximizing on-time delivery services, and Minimizing the total costs of supplied parts. Notably, the originality of this study lies in the following aspects: 1) Identifying the general structure of a supply chain (SC), with a particular focus on SC coordination among all product members; 2) Investigating existing SC models and their modeling methods to ensure effective coordination of SC elements; 3) Developing a hybrid model of IVFRN-BWM and robust objective planning tailored to the agile and flexible supply chain under uncertain circumstances; and 4) Identifying appropriate scenarios and cases to validate the proposed models, thereby establishing their validity.

This article aids decision-makers and managers in making informed choices regarding the selection of optimal suppliers and determining the appropriate allocation of parts to each supplier, considering the unique circumstances of individual companies.

Liu et al. [9] conducted a study with the objective of comprehending the distinctive role of supply chain flexibility (SCF) in facilitating the successful implementation of green operations (GO) strategies, based on empirical evidence gathered from the automotive industry. Through an exploratory case study involving three car manufacturers, the researchers revealed that diverse GO strategies necessitate support from various dimensions of SCF. Particularly, the significance of each flexibility dimension is contingent on the level of innovation in green projects, the types of green procurement initiatives, and the strategic orientation adopted for green production projects. The case studies offered valuable insights into the intricate relationships between SCF and GO by identifying fundamental theoretical structures and their interactions at a lower layer in a systematic manner. In practical application, the study findings aid managers in evaluating which dimensions of SCF can make substantial contributions to their specific GO endeavors. Subsequently, managers can devise appropriate plans for development and flexibility to foster favorable outcomes. As a significant contribution to the Operations Management literature, this research enhances the understanding of the multidimensional impacts of SCF on GO.

Mediation analysis enables supply chain management researchers and practitioners to expand the boundaries of their current knowledge by examining how, when, and why lean, agile, flexible, and green relationships occur for capabilities, sustainability, and performance. However, only a limited number of studies have investigated this issue due to the complexities related to their implementation. The paper by Nasrollahi et al. [10] provides preliminary data on the capabilities, sustainability and performance in supply chain contexts of a detailed model. Also, a wide review of articles is presented in order to create basic motivation related to supply chain management paradigms, supply chain capability, sustainability and performance used to create the study model. This review and subsequent model are intended to support future theoretical and practical research of supply chain management paradigms across complex and inclusive relationships.

Hamzehlou's [6] research develops a tailored System Dynamics model for Iran's Pharmaceutical Supply Chain (PSC) amidst COVID-19. Highlighting agility's importance in modern business, the study derives SC indicators from theory and literature, crafts an SD model for the pandemic-affected PSC, and suggests three key strategies for optimal agility: investment, Human Capital Development (HCD), and prioritized project completion. These findings stress the need for precise resource allocation and strategic project management to bolster PSC resilience amid adversity.

3. Research framework

This research employs a dynamic system modeling approach, which is approximate and non-definitive in nature owing to its inherent properties. Consequently, model simulation is conducted in this project to scrutinize the variables of supply chain flexibility, supply chain agility, and supply chain profitability, while exploring the interrelationships and impacts of various factors on these variables. The method adopted for this research is an applied research method.

The present research is characterized as a quantitative-qualitative study, wherein the required information was collected through a comprehensive review of previous studies. Initially, the literature on the subject was utilized to identify the research variables and their interrelationships. To gather data and determine the factors influencing supply chain flexibility, supply chain agility, and supply chain profitability, valid articles and insights from expert opinions were incorporated in this endeavor.

This research employed the following methods to gather information:

1. Document and library study
2. Expert consultations

To address the research questions, the system dynamics approach was utilized to review and analyze the data, focusing on two fundamental factors: product inventory and supply efficiency. Further elaborations regarding the model are presented in this section.

4. Data analysis

4.1. Modeling

Following the examination and evaluation of the proposed criteria by expert opinions, the identified criteria were incorporated into the model, and the interrelationships between them were represented as a cause-and-effect model in Figure 1. Subsequently, in Figure 2, all modes, rates, and auxiliary variables were precisely delineated.

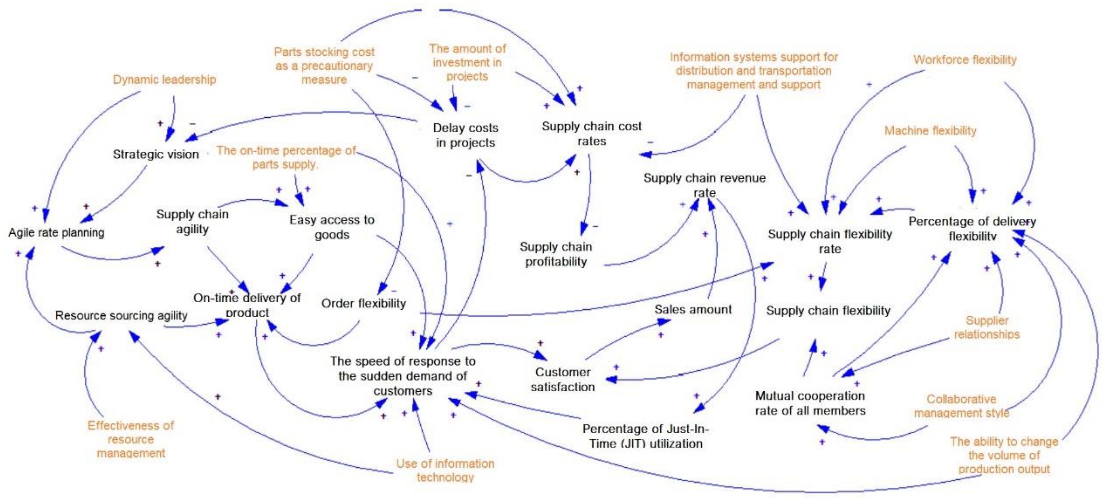

Figure 1: Cause and effect diagram

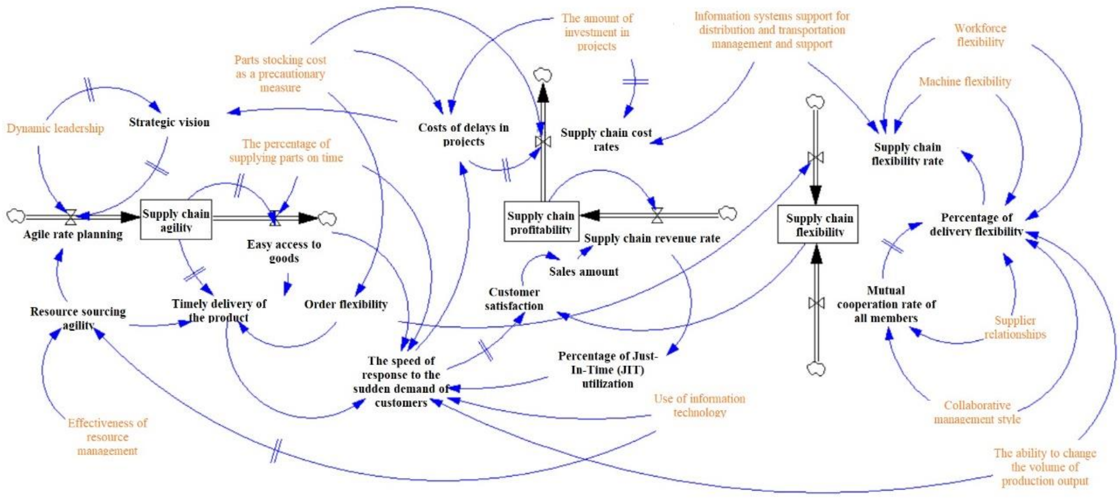

Figure 2: Flow chart of the model

4.2. Model structure validation

4.2.1. Boundary adequacy test

In this test, an assessment is conducted to ascertain the presence of factors influencing the model. As previously mentioned, these factors were identified through prior studies and experts' opinions, confirming their importance from these sources. Additionally, to determine the indispensability of these parameters, some of the crucial factors were removed, and the system's behavior was evaluated accordingly. The results of the model, post-omission of each factor, are presented below.

Figure 3 illustrates the impact of excluding the "planning agility rate" factor, which significantly influences supply chain agility. Not considering this variable in the simulation (though not its absence in the real world) demonstrates the necessity to reconsider all variables and their interrelationships. Disregarding this factor leads to a virtual decline in performance, deviating from actual conditions.

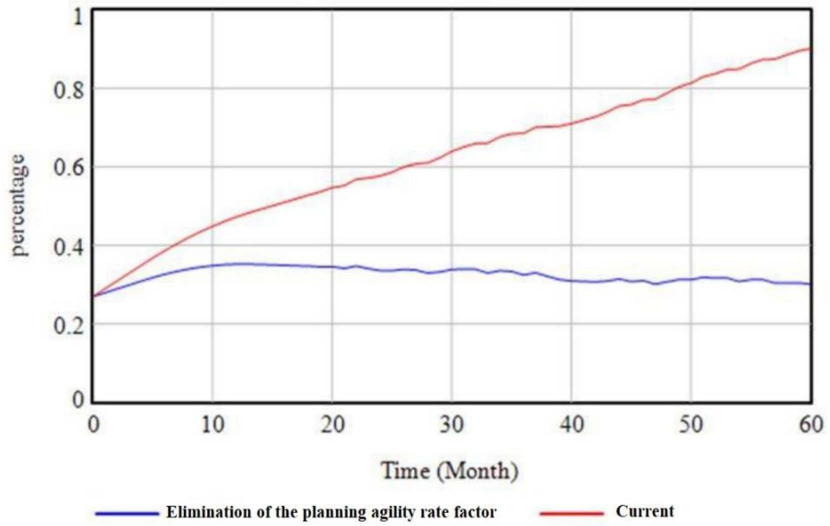

Figure 3: The effect of removing the planning agility rate factor on supply chain agility

Figure 4 showcases the effect of removing the "customer satisfaction" factor, which directly influences supply chain profitability. Neglecting this variable also results in a virtual decline in supply chain profitability. Enhanced customer satisfaction translates to increased purchases and elevated sales, thereby positively impacting profits.

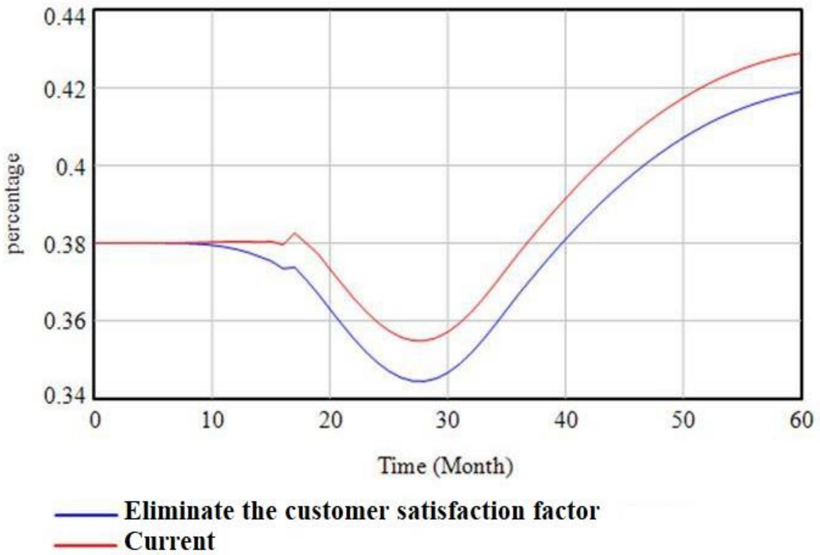

Figure 4: The effect of removing the customer satisfaction factor on the profitability of the supply chain

Therefore, the removal of this factor equates to zero, leading to the conclusion that its absence results in a decrease in sales and subsequent profitability.

Figure 5 depicts the impact of removing the "workforce flexibility" factor. The analysis shows that labor force flexibility positively influences supply chain flexibility, and its exclusion diminishes the overall supply chain flexibility. Given that a significant portion of the supply chain involves human resources, the influence of these resources on the chain cannot be disregarded.

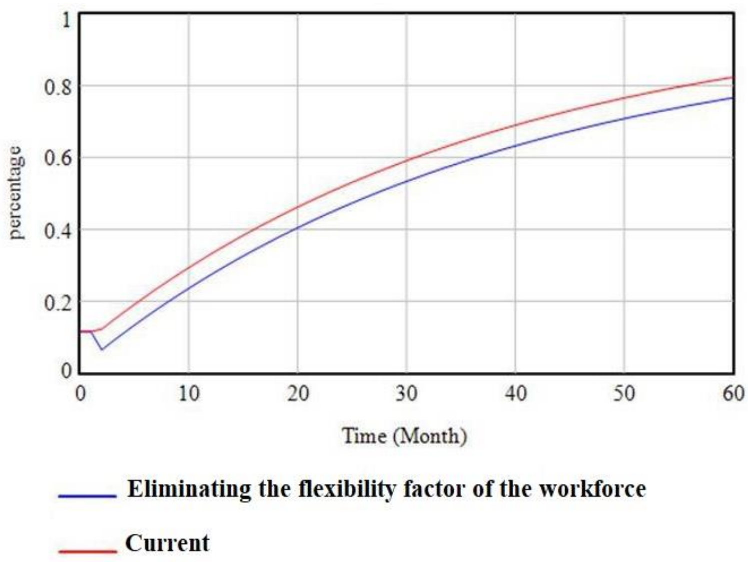

Figure 5: The effect of removing workforce flexibility factor on supply chain flexibility

As evident from these effects, the flexibility of these resources also influences the flexibility of the entire supply chain, and removing this flexibility leads to a reduction in overall chain flexibility.

4.2.2. Structure verification test

In summary, the validation of the structure of a system dynamics model entails ensuring that the relationships utilized within the model adequately represent real-world connections in line with the study's objectives. The equations pertaining to the model were written in the Vensim software environment for this research, and the software has confirmed the accuracy of the model's equation structure.

4.2.3. Parameters verification test

In this research, the evaluation of model parameters and factors was conducted through a comprehensive examination of previous studies and a comparative analysis with the reference model. Subsequently, expert consultations were sought to validate these identified parameters. Following the elimination of similar items, these parameters are presented in Table 1 for reference.

Table 1: Factors influencing the profitability, agility, and flexibility of the supply chain

Row	Variable	References
1	Agile rate planning	[11]
2	Resource sourcing agility	
3	Timely delivery of the product	
4	Easy access to goods	
5	The speed of response to the sudden demand of customers	
6	Dynamic leadership	[12]
7	Strategic vision	
8	Mutual cooperation rate of all members	
9	Use of information technology	
10	Supply chain cost rates	[13]
11	Collaborative management style	
12	Supplier relationships	

13	**Effectiveness of resource management**	
14	**Percentage of Just-In-Time (JIT) utilization.**	
15	**Customer satisfaction**	[6]
16	**Order flexibility**	[14]
17	**The amount of investment in projects**	
18	**The percentage of supplying parts on time**	
19	**Costs of delays in projects (due to lack of logistics agility)**	
20	**Supply chain revenue rate**	
21	**Parts stocking cost as a precautionary measure**	
22	**Percentage of delivery flexibility**	[15]
23	**The ability to change the volume of production output**	[16]
24	**Supply chain flexibility rate**	
25	**Information systems support for distribution and transportation management and support**	
26	**Workforce flexibility**	[17]
27	**Machine flexibility**	
28	**Supply chain flexibility**	
29	**Supply chain agility**	
30	**Supply chain profitability**	

4.2.4. Extreme condition test

In this test, the model's behavior is examined under extreme conditions by setting the inputs at their lowest or highest limits. The Boundary Adequacy Test section assesses the state of variables under infinity conditions (maximum value).

In the first situation, dynamic leadership is set at its lowest level (Figure 6):

A low level of dynamic leadership results in a significant decrease in supply chain agility. The organization's movement and adaptability heavily rely on its leadership. When the organization lacks suitable leadership that can effectively adapt to changing conditions and provide appropriate guidance, its performance suffers, leading to a negative impact on its agility.

Figure 6: The behavior of the model in the state of dynamic leadership is set at its lowest level and its effect on the agility of the supply chain

In the second situation, the response speed to sudden customer demand is set at its lowest level (Figure 7):

In the second situation, if the speed of responding to sudden customer demand tends to decrease, as depicted in Figure 7, the profitability of the supply chain also decreases. It is common in business for customers to place orders without prior planning. However, in the context of intense competition among companies, the key to success lies in a company's ability to swiftly meet these sudden and unplanned requests. The broader the coverage of these demands, the more it can lead to increased profitability for the organization due to two main reasons: first, an increase in sales; and second, an enhancement in customer satisfaction and loyalty. Consequently, as the speed of this response declines, nearing zero (i.e., removal of the factor), the profitability will substantially decrease.

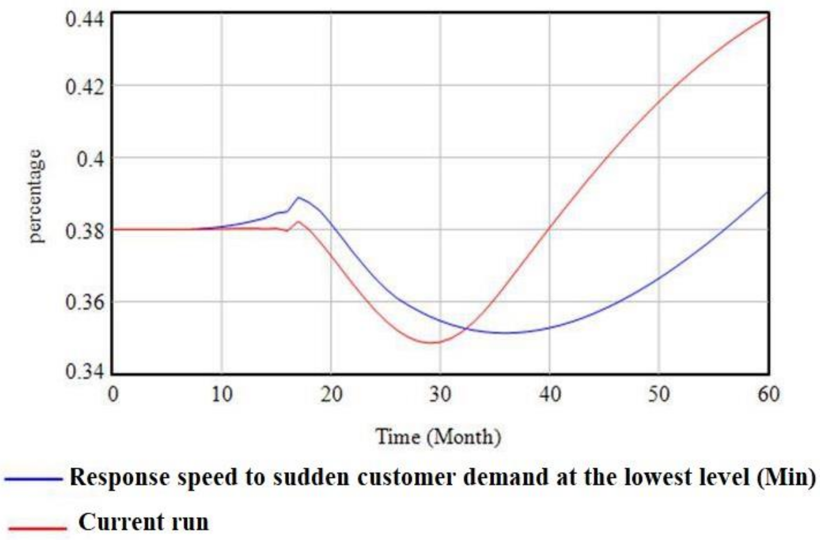

Figure 7: The behavior of the model in response speed to sudden customer demand is set at its lowest level and its effect on the profitability of the supply chain

4.2.5. Integration error test

In this test, the sensitivity of the model results to the choice of the time period is examined. The original 60-month time period of the model is changed to 96 months. The behavior of the model and the factors influencing the performance show no significant change, indicating that the model remains stable and the factors affecting the performance still exhibit improvements when controlled.

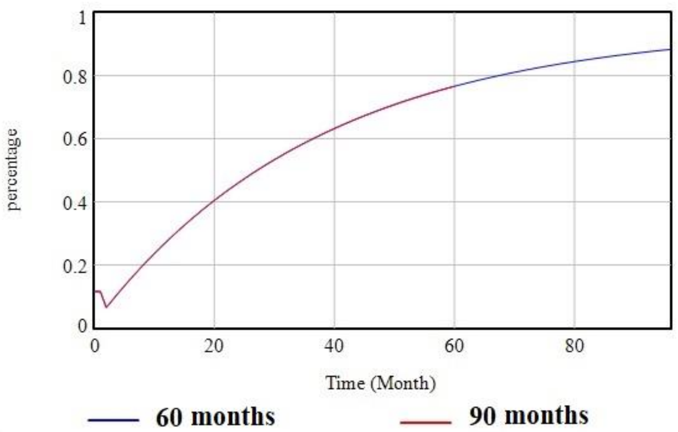

Figure 8: Model outputs in 60 and 96 months (two outputs overlap)

4.2.6. Behavioral reproduction test

The behavior reproduction test evaluates whether the model accurately reproduces and displays the behavior of the system in real conditions. Based on extensive reviews of previous studies, the researcher believes that this research includes the relevant variables that affect the efficiency of the supply chain, thus enabling the prediction of the system's behavior after identifying the criteria. Figure 9 demonstrates that by controlling the factors influencing performance, the profitability of the supply chain can be increased. However, there are numerous factors involved in improving performance, which necessitate more time for coordination.

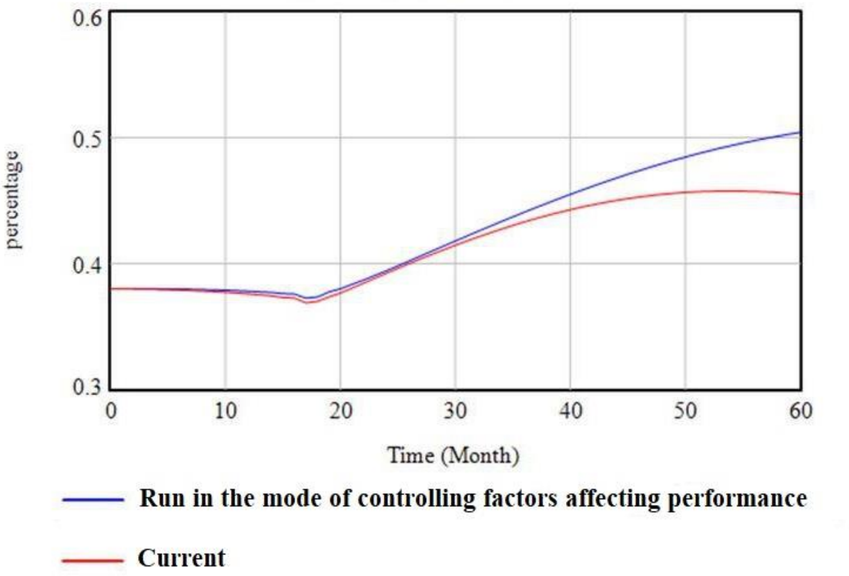

Figure 9: System behavior (supply chain profitability) after controlling factors

4.2.7. Sensitivity analysis test

In the subsequent stage of simulating the system and examining the behavior of each variable, the investigation of variable changes and their corresponding behavior should be conducted by the system. This aspect has been tested and demonstrated by implementing changes in the parameters as illustrated in the previous sections and the figures corresponding to these alterations.

4.3. Examining the performance of the model in different scenarios

In the final step, the factors of the model are thoroughly analyzed and examined to ascertain their extent and nature of influence on the main research variables. Subsequently, various scenarios are defined by specifying different values for the influential indicators to identify feasible strategies and ensure seamless implementation. This step aims to chart a practical path towards effective strategies and smooth execution.

In this research, the factors with significant impacts on the state and rate variables were identified based on the opinions of experts and relevant scientific studies, including Raza and Faisal [11], Alzoubi and Yanamandra [12], Choi et al. [13], Kim and Chai [6], Pericas Clavé [14], GÜNGÖR [15], and SAYIN [16]. To explore different outcomes, four scenarios were devised by varying the values of these influential indicators (as shown in Table 2). Figure 10, 11, and 12 illustrate these scenarios. The selection of variables and their combinations in each scenario was confirmed by experts' approval. Table 2 presents the values for each scenario in percentage, reflecting the extent of decrease or increase in the variables based on their nature.

Table 2: Research scenarios

Variable	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Dynamic leadership	10	15	20	25

Effectiveness of resource management	13	9	15	12
Parts stocking cost as a precautionary measure	-5	-7	-8	-12
The percentage of supplying parts on time	8	13	12	13
Use of information technology	11	14	12	13
The amount of investment in projects	12	7	10	13
Information systems support for distribution and transportation management and support	3	5	7	10
Workforce flexibility	5	10	15	20
Machine flexibility	2	3	4	5
Supplier relationships	3	-2	4	-3
Collaborative management style	3	5	7	10
The ability to change the volume of production output	1	3	2	4

4.3.1. Scenario 1

The percentages for the influential indicators in the research are as follows: dynamic leadership is increased by 10%, resource management effectiveness by 13%, supply of parts on time by 8%, use of information technology by 11%, volume of investment in projects by 12%, information systems support from distribution and transportation management and support by 3%, workforce flexibility by 5%, machinery flexibility by 2%, supplier relations by 3%, collaborative management style by 3%, and the ability to change production volume by 1%. Conversely, the cost of stocking parts for precaution is decreased by 5%.

4.3.2. Scenario 2

A 15% increase in dynamic leadership is observed, alongside a targeted 9% improvement in resource management effectiveness. Moreover, there has been a reduction of 7% in the cost of storing parts for safety. Conversely, a 13% increase in the percentage of parts provided on the due date has been recorded. Supplier relations, however, have experienced a decrease of 2%.

Information technology utilization demonstrates a 14% rise, while investment in projects has increased by 7%. Support from the management of distribution and transportation information systems and support systems has seen a growth of 5%. Additionally, the flexibility of the workforce has increased by 10%, and the flexibility of machines has improved by 3%. A 5% increase in the implementation of a collaborative management style has been noted, along with a 3% enhancement in the ability to change the volume of production output.

4.3.3. Scenario 3

A notable 20% increase in dynamic leadership has been observed. Additionally, a 15% enhancement in the effectiveness of resource management is being considered. It is worth noting that an 8% reduction in the cost of storing parts has been achieved.

Furthermore, a 12% increase in the index of parts supply on the due date is anticipated. Information technology utilization will witness a 12% rise, while investment in projects is expected to experience a 10% increase. Moreover, a substantial 7% growth is anticipated in the support of information systems by the management of distribution and transportation. The flexibility of the workforce is predicted to improve by 15%, while the flexibility of machines is projected to see a 4% increase. Additionally, supplier relations and collaborative management style are both expected to observe a 4% rise. Lastly, the ability to change the volume of production output is estimated to increase by 2%.

4.3.4. Scenario 4

A 25% increase in dynamic leadership has been observed, accompanied by a 12% enhancement in the effectiveness of resource management. Furthermore, there has been a reduction of 10% in the cost of storing parts. Conversely, there has been a 13% increase in the index of parts provided on the due date. Additionally, supplier relations have experienced a decrease of 3%.

In the next step, the model is executed, and the state variables are considered for four scenarios based on the changes in Table 2 variables. The results for three state variables, namely supply chain profitability, supply chain agility, and supply chain flexibility, are presented in Figures 10, 11, and 12, respectively.

Figure 10 displays the simulation results for the four defined scenarios, with scenario number 1 exhibiting the best performance for the supply chain profitability mode variable. In Figure 11, the simulation results for the four scenarios are presented, indicating that scenario number 3 demonstrates the best performance for the supply chain agility mode variable. Additionally, Figure 12 illustrates the results of the simulation for the four defined scenarios, with scenario 3 displaying the best performance for the supply chain flexibility mode variable.

Based on the findings from Figure 11 and considering the objective of achieving high profitability rather than high agility and flexibility, it is evident that scenario 1, involving a 10% increase in dynamic leadership, a 1% increase in the effectiveness of resource management, a 5% reduction in the cost of storing parts, an 8% increase in the percentage of parts supply on the due date, an 11% utilization of information technology, a 12% investment in projects, a 3% support of information systems from the management of distribution and transportation, a 5% improvement in the flexibility of the workforce, a 2% enhancement in the flexibility of machines, a 3% improvement in supplier relations, and a 1% increase in the ability to change the volume of production output, yields the optimal state for the variables influencing the model. These values were determined and reviewed considering various conditions related to suppliers, manufacturers, distributors, inventory, customer satisfaction, and supply chain costs, with insights from relevant studies and expert consultations.

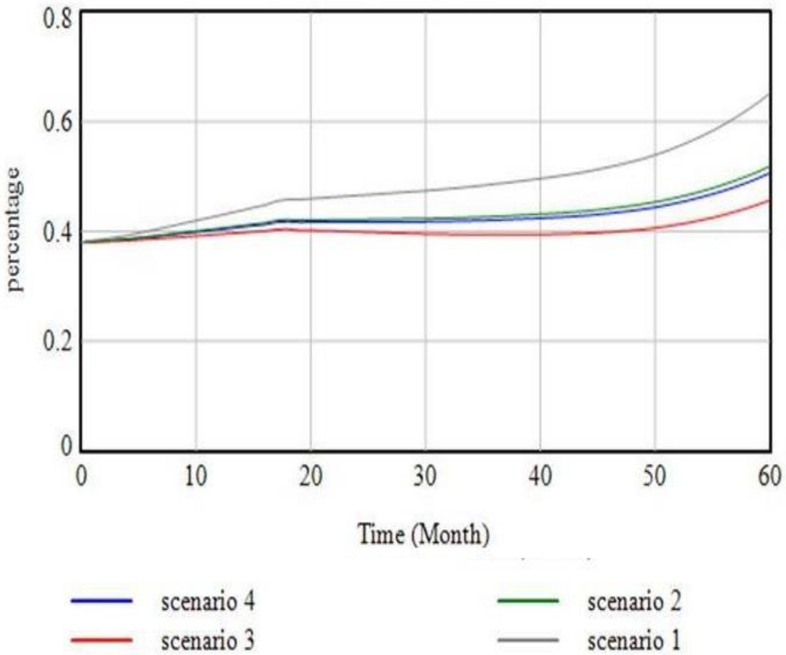

Figure 10: Different scenarios in the profitability mode variable of the supply chain

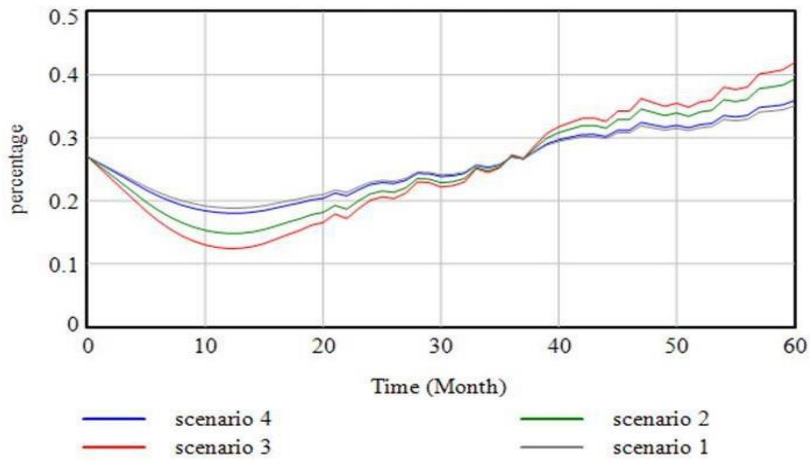

Figure 11: Different scenarios in supply chain agility mode variable

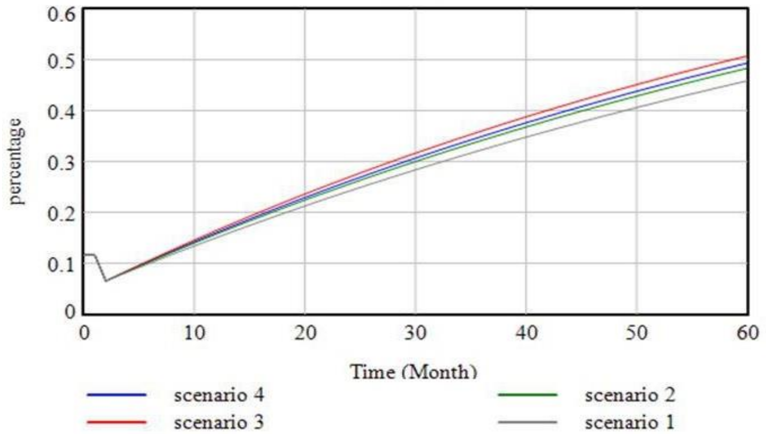

Figure 12: Various scenarios were considered for the supply chain flexibility mode variable

5. Discussion

The results indicate that profitability cannot be solely achieved through agility and flexibility. These findings establish that efforts to maximize profitability should not solely focus on increasing agility and flexibility. Instead, the highest levels of profitability, at 35.06% and 45.8% respectively, are attained when both agility and flexibility are optimally balanced. Consequently, it is demonstrated that the expenditure on enhancing agility and flexibility proves to be economically viable. Beyond these optimal levels, further investment in increasing agility and flexibility does not yield profitable returns.

To achieve this desired state, researchers must delineate strategies that effectively influence the relevant factors, bringing them closer to the identified optimal values. Such strategies encompass enhancements in information technology systems, fostering improved supplier relationships, determining optimal stock levels to mitigate shortages, executing resource management proficiently, and precise time planning for timely deliveries. Collaborative management among chain members and strategic investments to support these initiatives also hold significant sway over the research objectives. Employing these strategies judiciously will enable researchers to advance towards the desired optimal state of profitability while maintaining a well-balanced approach to agility and flexibility.

6. Conclusion

The agility of the supply chain, denoting its capacity to respond to evolving demands and timely deliver goods to customers, exerts a positive influence on on-time product delivery. The acceleration in product delivery fosters prompt responses to sudden customer demands. Consequently, such enhanced responsiveness leads to reduced project delays and the corresponding cost implications. As these costs diminish, the likelihood of attaining the strategic vision increases, facilitated by resource conservation and the optimal utilization of time through the avoidance of delays. Consequently, as the plans align more closely with the strategic vision, the level of planning agility also rises.

An augmented income rate within the chain enables greater investments in Just-in-Time (JIT) practices. This capacity is bolstered by both the increased capability to invest and the heightened demand for JIT brought about by an upsurge in sales volume. Concurrently, the implementation of JIT fortifies the production sector, enabling it to adeptly respond to sudden demands, thereby accelerating the coverage of these demands. By achieving heightened responsiveness and swift gratification of customer needs, it becomes evident that customer satisfaction levels rise significantly. Such heightened satisfaction, in turn, fosters repeat purchases, culminating in an overall increase in profitability.

In the model validation section, the interplay of variables and their effects on one another has been demonstrated, affirming the model's correctness in behavior representation. Furthermore, in the specified scenarios, the research has undergone comprehensive analysis, encompassing the evaluation and determination of the type and magnitude of their impact on the main factors and variables constituting the focal points of the study. Subsequently, predictions have been made concerning the effects of alterations in these variables and the identification of their optimal states.

7. Suggestions for further research

The model employed in this research focused on the consideration of a singular supplier at a single level, while acknowledging the possibility of suppliers expanding across various vertical or horizontal levels. In such instances, discussions may arise concerning the timely accessibility of all requisite materials for product manufacturing and the imperative to synchronize orders encompassing diverse lead times.

The distributor section of this model incorporates the inclusion of a distribution center, and the investigation of potential scenarios involving multiple distributors aims to address the challenges associated with efficient distribution of goods across diverse distribution centers, thereby mitigating the risk of shortages.

The examination of government policies and their impact on organizational performance can be undertaken, encompassing the analysis of diverse policies and their resultant effects.

Through the repetition of the modeling process, while acknowledging the inherent limitations of the modeling concept, it is evident that all models inherently possess an element of incompleteness. This arises from the fact that a model, by its very nature, constitutes a simplified representation of entities and relationships within the real-world context. Consequently, with each iteration, the incorporation of additional details into the model allows for its continuous enhancement, resulting in a more intricate and comprehensive representation compared to its previous versions.

References

[1] A. Naugle, S. Langarudi and T. Clancy, "What is (quantitative) system dynamics modeling? Defining characteristics and the opportunities they create," *System Dynamics Review,* pp. 1-14, 2024.

[2] E. Manfredi and P. Capik, "A case of trust-building in the supply chain: Emerging economies perspective," *Strategic Change,* vol. 31, pp. 147-160, 2022.

[3] N. Kazantsev, O. Petrovskyi and J. M. Müller , "From supply chains towards manufacturing ecosystems: A system dynamics model," *Technological Forecasting and Social Change,* vol. 197, no. 1, 2023.

[4] M. Tanweer Ahmad, M. Firouz and S. Mondal, "Robust supplier-selection and order-allocation in two-echelon supply networks: A parametric tolerance design approach," *Computers & Industrial Engineering,* vol. 171, 2022.

[5] G. Grama, System Dynamics Based Analysis of Global Semiconductor Supply Chain Disruptions, Washington : The George Washington University ProQuest Dissertations Publishing, 2023.

[6] D. Ivanov , "Viable supply chain model: integrating agility, resilience and sustainability perspectives—lessons from and thinking beyond the COVID-19 pandemic,"

Annals of Operations Research, vol. 319, no. 1, pp. 1411-1431, 2022.

[7] A. Wiśniewska-Sałek, "Managing a Sustainable Supply Chain – Statistical Analysis of Natural Resources in the Furniture Industry," *Management Systems in Production Engineering,* vol. 29, no. 3, pp. 227-234, 2021.

[8] S. Demir and T. Paksoy, "Fundamental Concepts of Smart and Sustainable Operations and Supply Chain Management," in *Smart and Sustainable Operations and Supply Chain Management in Industry 4.0*, CRC Press, 2023.

[9] S. Fayezi, A. Zutshi and A. O'Loughlin, "Understanding and Development of Supply Chain Agility and Flexibility: A Structured Literature Review," *The International Journal of Management Reviews,* vol. 4, no. 19, pp. 379-407, 2016.

[10] T. Chan Alan, W. Eric and K. Moon Karen, "The effects of strategic and manufacturing flexibilities and supply chain agility on firm performance in the fashion industry," *European Journal of Operational Research,* vol. 259, no. 2, pp. 486-499, 2017.

[11] M. Kim and S. Chai, "The impact of supplier innovativeness, information sharing and strategic sourcing on improving supply chain agility: Global supply chain perspective," *International Journal of Production Economics,* vol. 187, pp. 42-52, 2017.

[12] A. Hendalianpour, M. Fakhrabadi, X. Zhang, M. Feylizadeh, M. Gheisari, P. Liu and N. Ashktorab, "Hybrid Model of IVFRN-BWM and Robust Goal Programming in Agile and Flexible Supply Chain, a Case Study: Automobile Industry," *IEEE Access,* vol. 7, pp. 71481-71492, 2019.

[13] Y. Liu, Y. Zhang, L. Batista and K. Rong, "Green operations: What's the role of supply chain flexibility?," *International Journal of Production Economics,* vol. 214, pp. 30-43, 2019.

[14] M. Nasrollahi, M. Safaei and N. Mahmoodi, "A Mathematical Model for Integrated Green Healthcare Supply Network Design," *International Journal of Business Analytics,* vol. 8, no. 1, pp. 58-86, 2021.

[15] M. Hamzehlou, "System dynamics model for an agile pharmaceutical supply chain during COVID-19 pandemic in Iran," *PLOS ONE,* vol. 19, no. 1, p. e0290789, 2024.

[16] M. Raza and S. Faisal, "Impact of Strategic Flexibility on Supply Chain Agility: A qualitative case study of textile companies in Pakistan," Jönköping University, Sweden, 2023.

[17] H. Alzoubi and R. Yanamandra, "Investigating the mediating role of information sharing strategy on agile supply chain," *Uncertain Supply Chain Management,* vol. 8, no. 2, pp. 273-284, 2020.

[18] T. Choi, T. Netland, N. Sanders, M. Sodhi and S. Wagner, "Just-in-time for supply chains in turbulent times," *Production and Operations Management,* vol. 32, pp. 2331-2340, 2023.

[19] E. Pericas Clavé, "The real challenges in the Manufacturing Supply Chain," Illinois Institute of Technology, Chicago, 2017.

[20] A. GÜNGÖR, "The Mediating Role of Flexibility and Agility in the Effect of Supply Chain," *International Journal of Business & Economic Studies,* vol. 3, pp. 102-111, 2021.

[21] A. SAYIN, "The Effects of Information Systems on Supply Chain and Operating Performance - Analysis of the Retail Industry," *MANAS Journal of Social Studies,* vol. 9, no. 3, pp. 1627-1639, 2020.

[22] J. Manders, M. Caniëls and P. Ghijsen, "Supply chain flexibility: A systematic literature review and identification of directions for future research," *The International Journal of Logistics Management,* vol. 28, no. 4, pp. 964-1026, 2017.

[23] A. Rojo, M. Stevenson, F. J. B. Montes and M. Nieves Perez-Arostegui, "Supply chain flexibility in dynamic environments: The enabling role of operational absorptive capacity and organisational learning," *International Journal of Operations & Production Management,* vol. 38, pp. 636-666, 2018.