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SYSTEM DYNAMICS: AN APPROACH TO MODELING SUPPLY CHAIN PERFORMANCE MEASUREMENT

Peide LIU[1,5*], Morteza ATIFEH[2], Mohsen KHORSHIDNIA[3], Seyed Ghiasuddin TAHERI[4]

[1]*School of Business Administration, Shandong Women's University, Jinan, Shandong, China*
[2]*Department of Engineering, College of Farabi, University of Tehran, Tehran, Iran*
[3]*Industrial Engineering Department, Islamic Azad University, Najafabad Branch, Isfahan, Iran*
[4]*Department of Industrial Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran*
[5]*Shandong Key Laboratory of New Smart Media, Jinan, Shandong, China*

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Abstract. The complexity of goods and services in the current world has caused individual companies that do not have the help and cooperation of other organizations to face many problems for their survival. In this paper, a system dynamics model was proposed by creating a cause-effect curve to increase supply chain (SC) performance with an emphasis on agility and flexibility (AAF) indicators. The proposed model aimed to reduce cost and delivery time and increase customer satisfaction by considering AAF indicators. To this end, the concepts used were first introduced. Afterward, the important goals were identified by reviewing the existing literatures and interviewing experts in the field of AAF indicators in the studied SC. In the next step, the model was constructed by determining the cause-and-effect (CAE) relationships between the variables. Finally, by developing and simulating different scenarios, the results showed that AAF alone and absolutely cannot enhance profitability. By implication, to increase profitability, AAF do not need to be enhanced to the highest level, but an optimal point must be found. Finally, an optimal level of AAF was estimated. by using this system and considering that this system supports the production line, the ability to respond to sudden demands is increased and as a result, the speed of covering these demands increases.

Keywords: supply chain, performance evaluation, modeling, system dynamics, agility, flexibility.

JEL Classification: C15, C30, C44, C80.

Introduction

Intense competition in the modern global markets, the supply of new products with a short presence in the market, and the peak of customer expectations have forced businesses to invest in and focus on their Supply Chains (SCs) (Liu & Hendalianpour, 2021; Hendalian-

*Corresponding author. E-mail: *peide.liu@gmail.com*

pour, 2020). Business competition today is no longer between two individual companies but between SCs (Liu et al., 2021a, 2021b; Hendalianpour et al., 2018). Thus, SC Management (SCM) has become an important tool for companies to be able to manage quality, keep customers satisfied, and stay competitive (Liu et al., 2021a, 2021b; Hendalianpour et al., 2016). It can be emphatically suggested that the best way to regulate the correct and rapid responses to systems issues is to record and examine their important function points in the form of a future scenario that measures the past and present behavior of the system environment. Registering this scenario requires knowledge or a technique that uses a systemic approach to correctly identifying problems and showing the fastest and most accurate response to solve problems. This knowledge is called System Dynamics (SD) (Hosseini et al., 2021).

SC Performance (SCP) evaluation refers to the extensive activities of the SC to meet the needs of the end customer, which involves the ability to access the product, timely delivery, and the capacity needed in the SC for proper performance to meet the needs of the end customer (AlKahtani et al., 2019). SCP transcends the company's boundaries because it includes raw materials, parts, by-products, and end products, and the distribution of the product through various channels to the customer (Liu et al., 2021a, 2021b). To succeed in a new business environment, the SC needs continuous improvement, and to do this, it is necessary to evaluate the SCP and extract factors affecting it (Tarafdar & Qrunfleh, 2017). Currently, senior executives do not only focus on their company's performance but also SCP (Alqudah et al., 2020). Hausman believes that to improve SCP, we need to define new performance metrics so that we can evaluate SCP instead of assessing the performance of a business individually. In SCP evaluation, not only the performance of the parent company is evaluated, but also a network of relationships between SC partners is assessed. The performance appraisal of the SC system enables the organization (Umam & Sommanawat, 2019):

- To review, evaluate and control the performance.
- To use the same methodology and criteria in evaluation at the organization level.
- To make decisions within a systematic framework.

The issue of measuring business performance is a topic that has been widely discussed in the literature and is considered a vital element in effective planning, control, and decision making in the current competitive world (Aslam et al., 2018). Many authors have studied SCP evaluation (Burgess et al., 2006). Recent studies have addressed a set of environmental, social, and economic factors. SC managers need systems to measure the productivity and effectiveness of their operations because productivity performance measurement has increasingly become an issue or a strategic initiative that all companies pay attention to (Simão et al., 2021). Thus, there is a need to develop a performance indicator to evaluate performance. In SCP evaluation, we look for a system to evaluate the performance of the existing SC and to provide an integrated framework of different SC expectations and functions (Rasool et al., 2021).

Classical methods such as structural and regression models, although relatively successful in performance evaluation and forecasting, their outcomes were not satisfactory for researchers in this field because these methods generally rely on information obtained from historical events (Lopez et al., 2021). A SD is something that exists because a static system is a cross-section or a particular view of a dynamic system that is assumed to be static for ease of analysis with one or more simplifying conditions (Bagheri et al., 2015). In systems science, static means that system parameters or state variables do not change over time. In dynamic systems, complex and dynamic issues and problems seem to have at least two aspects: First, issues that have a dynamic and quantitative nature (Wang et al., 2020). For instance, employment fluctuations in industry and the relationship between urban tax reliefs and the quality of citizens' life are dynamic problems. The second aspect is the existence of feedback theory. Feedback exists in engineering systems, technical structures, control systems, social sciences, and human societies. Dynamic systems thinking and practices apply to dynamic problems that have feedback loops. Organizations, economics, societies, and in fact all systems that deal with humans in some way, or even mechanical and electronic systems and the like, are considered feedback loop systems (Bueno-Solano & Cedillo-Campos, 2014; Qudrat-Ullah et al., 2018). Examining, studying, and modeling these systems provide a tool for understanding their behavior and performance outcomes. Addressing this issue is important in that first, organizations seek to gain a competitive advantage and reach global standards to gain benefit by integrating the SC. Second, many organizations still have traditional SCs that significantly increase tangible and intangible production costs. Third, a review of previous studies indicates that social and environmental issues have received less attention in Iran and more focus has been on the economic aspect. The fourth problem is the inadequacy of the existing model as well as the lack of consensus in this area.

A review of the literature indicates that most studies in SCP have focused on suppliers. According to Hasani and Hosseini (2011), one reason is the pressure they feel from their customers. They also concluded that the focus on AAF in the manufacturing sector can be explained by two factors. First, research has traditionally focused on manufacturing and production issues, leading to the development of the Agile SC (ASC) in the literature. Since all previous studies have addressed the identification and rating of the factors affecting AAF, rather than analyzing the impact of these factors, they have mostly used decision-making and statistical methods to evaluate performance. Thus, the SD approach has not been employed for SCP evaluation. For this purpose, this study first identifies the effective indicators in evaluating the performance of the sustainable SC and then analyzes their impact using the SD approach. SD can be used as an efficient way to analyze changes. In fact, the dynamic model helps us to more accurately understand how these indicators affect each other. Another advantage of dynamic modeling is the effective analysis in solving complex problems with a large number of variables. Using SD as an approach to analyzing the impact and change of sustainable SC factors in the future can effectively help in future decision-making. Accordingly, the present study faces the following questions:

- What are the main variables affecting SC Agility (SCA) and SC flexibility (SCF) and how do they behave?
- How is the relationship between variables in the SCA and SCF model?
- Can the behavior of the main variables of the SC model be described, explained, and predicted using the SD model?
- What are the optimal policies to improve the performance of the SCA and SCF using the SD approach?

The rest of the study is shown as follows. In Section 1, previous studies are reviewed. Section 2 addresses the research method and the SD model. To do this, we will be different scenarios are defined and simulated to model the indicators affecting the AAF indicators in the SC in the form of a CAE model (CAEM). Section 3 proposed the SD model and results. With the approval of the variables by experts, the relationship between these variables will be done. Finally, the causal diagram will be plotted using Vensim software. Finally, the last section concludes the study.

1. Literature review

SC research that was initially developed on the topics of leanness and agility and their combination as flexibility (Christopher, 2016; Fadaki et al., 2020) by perspectives on flexibility and sustainability (Hendry et al., 2019; Wood et al., 2019; Christopher & Lee, 2004) followed by the advanced use of digital technologies and the fourth industry (Queiroz et al., 2020; Fosso Wamba et al., 2015). The following section provides a review of previous studies in this field.

Agile production is defined as the ability to respond to unpredictable market changes in a cost-effective way while relieving uncertainty. In many industries, drastic market changes demand more distinctive products in smaller volumes and with shorter delivery times. An uncertain environment challenges the SC response. Using a SD simulation, Helo (2000) showed how to incorporate agility in SCs. Three simulation models were analyzed: First, the effect of demand magnification on the SC was studied. In the second stage, the analysis was extended to consider the effects of increasing capacity. Finally, the trade-off between capacity utilization and lead time was discussed. Evidence from the implemented simulations and proven literature was provided.

In another study, Fayezi et al. (2017) reviewed the literatures on the concepts of SCA and SCF and analyzed 83 papers by a structured review technique. The identified articles focused on organizational and SCA and SCF. The gaps in understanding and development of SCA and SCF were identified and categorized based on conceptual, contextual, and methodological aspects. Stefanovic and Milosevic (2017) first performed an analysis of the current researches and then introduced the adaptive and integrated SC intelligence model in which the main components, the architecture and features were described, and the usefulness and applicability were introduced.

Chan et al. (2017) studied the major causes and effects of SCA at both the strategic and operational levels. They thought that two organizational strategic flexibility and manufacturing flexibility are the important causes to SCA, and strategic flexibility has an obvious effect on company performance while manufacturing flexibility does not. Focusing on SCA in the fashion manufacturing industry, the findings of the study contributed to the understanding of SCM. Kim and Chai (2017) examined the effect of supplier innovativeness on SC collaboration and SCA. This study offered valuable insights for academics and industry and demonstrated the positive impact of supplier innovativeness to facilitate collaborations in the SC. Wu et al. (2017) performed a case study to identify a set of SCA reinforcement attributes in which the fuzzy Delphi method was used to screen and eliminate unnecessary attributes. The findings showed that flexibility obviously affects process integration, information integration, and strategic alliances for environmentally friendly design in the SC followed by process integration that has the greatest impact on developing the competitive advantage from innovativeness. Tarafdar and Qrunfleh (2017) examined the mediating effect of SC practices on the relationship between ASC strategy and SCP. Malakouti et al. (2017) determined ASC among SMEs in the manufacturing-related services.

Braunscheidel and Suresh (2018) provided a new research vision of literature devoted to SCA, and then they proposed a set of SC initiatives as antecedents for the cultivation of agility. Rojo et al. (2018) investigated the relationship between environmental dynamics and SCF and assessed whether two dynamic capabilities, Operational Absorption Capacity (OAC) and Organizational Learning (OL), are requirements for the development of companies or not. Hypothetical relationships were tested using structural equation modeling. The findings showed that environmental dynamics are associated with OAC and OL, both of which creating SCF dynamics.

Cheung et al. (2018) examined the effects of a SC's IT architecture on SC capabilities (SCCs) and firm performance. Based on data collected from 162 companies, the results indicated that companies with different SC strategies tend to focus on different aspects of IT architectures. Furthermore, they showed SCC can enhance SCP. In addition, Wu et al. (2017) provided a set of models for designing agile SCs using dynamic planning modeling. This provides decision-makers with a systematic approach to analyzing one of the most important resource strategy decisions. In another study, Aslam et al. (2018) suggested market sensing, SCA, and SC adaptability as a coherent cluster of dynamic SCCs. The goal of this study was to learn how dynamic SCCs interrelate and their effect on SC ambidexterity. The results showed that a market-sensing capability is an antecedent of SCA and SC adaptability. Furthermore, SCA, directly, and SC adaptability, indirectly, affect SC ambidexterity. Gupta et al. (2019) studied the relationship between the smart SC and information system flexibility to get an overall greater SCF based on Organization Information Processing Theory (OIPT). Hendalianpour et al. (2019) examined the agile and flexible allocation of orders to suit the automotive industry, in which parts supplied by a single source were removed from the component set. Using a combination of mathematical modeling of robust ideal planning and IVFRN-BWM, attempts were made to obtain results that can meet the requirements of the developed model. Nikzad et al. (2019) proposed a basic mechanism through which enterprises can get SCA and increase business performance from a vendor perspective based on dynamic capability theory and probabilistic theory. Shekarian et al. (2020) examined the effect of SCF and SCA in improving SC responsiveness (SCR). Based on supply risk and demand risk, they assessed a SC from multiple aspects, including sites, transportation channels, product planning, and periods. Umam and Sommanawat (2019) investigated the relationship among SCF, strategic flexibility, production flexibility, and firm performance. AlKahtani et al. (2019) and Boubaker et al. (2019) did literature review on the assessment of SCA to give a comprehensive basis for future researches on SCA measurement and management.

In another study, Kawa and Maryniak (2019) identified the SCs' lean and agile approach based on the type of moving product, logistical solutions and SCM, and trends that form the image of SCs. Bai et al. (2020) studied the relationship between a new SSCF measures and CE-targeted performance based on the objective-DEMATEL. Liu et al. (2019) examined the specific role that can be played by SCF after using green operations strategies and the data from the automotive industry. Haq et al. (2020) examined the three main factors of SCA – namely strategic flexibility, employee behavioral flexibility, and (external) relationship integration. The sample under study was 147 SMEs in Pakistan that were collected through surveys and then modified using structural equation modeling and tested in MPlus software. Customer integration, employee behavioral flexibility, and strategic flexibility were found to have a direct impact on SCA. Furthermore, customer integration through strategic flexibility has an indirect impact on SCA.

Alzoubi and Yanamandra (2020) examined the effect of information sharing strategy in medium-size manufacturing companies on ASC practices for achieving SCP in UAE, and obtained that information sharing plays an important mediating role to achieve superior SCP. Alqudah et al. (2020) presented an extensive literature review about the measures associated with the SCM paradigms, SCC, sustainability, and performance. Roscoe et al. (2020) developed a hypothetical model to account for the independent and combined effects of internal and external process connection on SCA.

In another study, Nazempour et al. (2018) examined the relationship between SCA and Organizational Performance (OP) based on the data from Iran. The findings showed a positive relationship between SCA and OP with positive relationships for each SCA dimension (e.g., alertness, assertiveness, flexibility, accessibility, and speed). Keshavarz-Ghorbani and Pasandideh (2021) explained what topics have been studied, what areas need more attention, how the existing literature can be classified, and how the field can be moved forward. Díaz-Reza et al. (2020) developed a structural equation model that addressed four latent variables including employee performance, knowledge transfer, complexity, and SCF, which includes 17 observed variables. The latent variables were examined using six hypotheses tested with data from 269 respondents completing a questionnaire applied to the maquiladoras industry in Mexico. The findings indicated that the transfer of external knowledge into the SC is very important because it explains 44.6% of its complexity, 19.5% of employee performance, and also 10.6% of SCF.

Shaw et al. (2021) identified the important enablers, inhibitors, and benefits of achieving ESCPM as a practice in companies based on the data of 388 UK SC professionals in a three-phase empirical study. This study provided an up-to-date review of the factors influencing ESCPM practiced, highlighting the need for additional research in this area. Besides, Hanh Nguyen et al. (2021) proposed a model to explore the external and internal problems that reduced the coffee SC's efficiency based on the SCOR model in Kontum province, Vietnam. The achieved performance for the whole coffee SC was 68.28 with an average category. Xie et al. (2020) introduced the effect of Industry 4.0 on SCM, and developed a performance evaluation indicator system consisting of seven indicators which provides an efficient method to improve the performance of intelligent SCM.

A study by Shekarian et al. (2020) showed that both SCA and flexibility have a positive relationship with SCR. Furthermore, Braunscheidel and Suresh (2018) argued stated that it has been statistically proven that the right mix of various types of flexibility is effective in improving accountability in an organization. In another study, Dubey et al. (2018) showed that SCA increases responsiveness. In addition, Hendalianpour et al. (2019) showed that external flexibility strengthens a company's SCA. On the other hand, scholars such as Alqudah et al. (2020) have shown that in order to reduce supply and demand disruptions in the SC, SCR need to be improved by investing in enabling factors such as AAF. Umam and Sommanawat (2019) pointed out that each of these enablers has a positive effect on improving SCR. Since improved SCR reduces the effects of SC disruption, it negatively affects SC risks. Other scholars (e.g. Haq et al., 2020; Nikzad et al., 2019) have shown that by investing in flexibility and agility, SCR can be improved. Following the insights from the literature, this study aims to develop a SD model for SCR to examine two components of responsiveness: SCF and SCA. Thus, the contributions are stated as:

– Explaining the importance of SCP measurement by an SD model and its effects on agility, flexibility, and profitably;
– Proposing influential factors in SCP measurement on AAF;
– Establishing a connection between strategies and measurement criteria in SCP measurement;
– Designing a set of goals and developing an innovative strategy to better represent the causal-effect structure of the analyzed system, focusing on the concept of feedback loop and the use of tools such as causal-effect loop graph in SCP measurement.

2. Problem statement

SCM seeks to build trust between different components of the chain, exchange information about market needs, develop new products in a way that meets customers' needs, and establish a long-term relationship between different stages of the chain (Hendalianpour et al., 2020a, 2020b). SCM has an extensive scope that covers minor suppliers, major suppliers, internal operations, major customers, minor customers, and end consumers, and its main purpose is to satisfy end customers of the SC. Ivanov et al. (2019) consider SCM a concept that originated in the manufacturing industry. In fact, the first signs of SCM were evident in Toyota's just-in-time (JIT) production system. This system aims to reduce the inventory level and regulate the suppliers' interactions with the production line effectively and efficiently. After the emergence of the SCM approach in the Japanese automotive industry, as a subset of the production system, a change occurred in the conceptual space of SCM, and this type of management was introduced as one of the independent and main concepts in industrial management theory. In practice, SCM is a combination of specific domains in the conceptual space of management, including total quality management, business redesign process, and correct and timely production methods (Jha et al., 2021). Therefore, the SC can be considered a network of companies supplying raw materials, manufacturers, and distributors that are engaged in purchasing raw materials, converting these materials into semi-finished and final products, and distributing them to end customers (Rebs et al., 2019). Generally, a SC has multidimensional structures that require to adopt effective approaches to improve the growth in their systems and ensure efficient management of a set of tasks on a large scale. SCM mainly aims to optimize its performance through developing a modeling framework for analyzing and understanding the dynamic behavior of SCs.

This study seeks to improve SCP by designing a SD model with an emphasis on AAF indicators. Accordingly, it also seeks to reduce costs and delivery time and increase the satisfaction from customers by considering the AAF indicators. To do this, different scenarios are defined and simulated to model the indicators affecting the AAF indicators in the SC in the form of a CAEM. To this end, the concepts used are first introduced. Afterward, the important goals are identified by reviewing the literature and interviewing experts in the field of AAF indicators in the studied SC. In the first step, influential indicators in previous studies such as responsiveness, customer demands, market sensitivity, immediate reaction to change, sourcing flexibility, distribution flexibility, production flexibility, etc. will be examined. Then the effects of these indicators on delivery time, production and distribution costs, and customer satisfaction are examined. Furthermore, using these data, the state variables in the SD are defined, and different strategies are developed and tested. In the next step, using the outputs from the first step for the time horizon and different scenarios, an action plan for the obtained scenarios is formulated. In this study, modeling is performed through SD that is an approximate, not a definite model due to its properties. Therefore, in this project, model simulation is performed to examine the SC variables including flexibility, agility, and profitability, and their interrelationships and the impact of various factors on it. Thus, this study is an applied to Automobile companies that are conducted through the following steps:

- **Step 1:** Reviewing the literature and surveying subject-matter experts.
- **Step 2:** Analyzing effective factors, omitting, and revising them, and determining the final factors.
- **Step 3:** SD modeling by considering the selected factors and their interrelationships.
- **Step 4:** Validating and analyzing the results.

Figure 1 shows the steps taken to conduct this study.

As shown in Figure 1, the SD approach has been used in this study. To this end, using SD, all factors affecting the system are modeled and their behavior is analyzed by simulating the model. The results are used to predict the future values of the factors. The SD approach is described below.

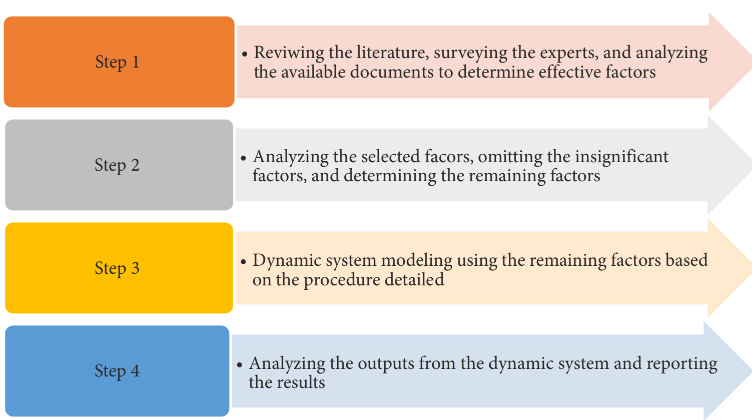

Figure 1. Steps taken to conduct the study

3. System dynamics

SD is with a set of qualitative tools for dynamic process analysis including causal-effect loop diagrams, stock-flow diagrams, and simulation and optimization diagrams (Yunna et al., 2015). These tools may examine different possible outcomes, proposing hypotheses for confusing data, discovering significant connections, categories, or thresholds among acceptable model sets. In addition, these tools also support reasoning based on the results of risk analysis, opportunities, or scenarios (Hosseini et al., 2014).

Now, the models and theories used to produce their results are developed based on some assumptions, beliefs, and values, so not all models are correct and systems thinking needs some degree of satisfaction (Sterman, 1989). According to Schwaninger and Groesser (2020), the steps taken under this approach are as follows:

1. Stating the problem.
2. Formulating dynamic model hypotheses.
3. Developing the simulation model.
4. Testing the model.
5. Developing the system alternatives and assessing them.

Figure 2 shows the steps taken in the modeling process. Library data and experts' opinions are used to identify the factors affecting SCF, SCA, and SC profitability (SCPR). Then, in the next step, the relationship between these causals and their effects on each other are examined according to the positive and negative values. After the final confirmation of the effects, the obtained data will be analyzed using Vensim software. The results of data analysis can be used for all SCs to identify the factors affecting these systems and optimize their performance. Besides, these results can be used to increase the efficiency of their systems and resources.

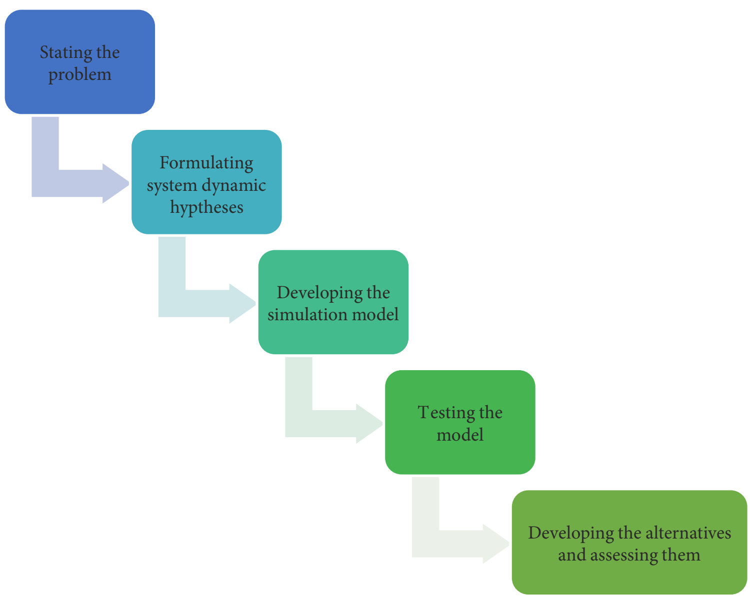

Figure 2. Steps taken in the modeling process

3.1. Modeling time Horizon

Selecting the right time horizon plays a key role in the outputs from SD and helps produce more realistic results. According to Olivares-Aguila and ElMaraghy (2021), since the effects of learning and feedback loops are not short-term under normal conditions, the time horizon for causal loops is short. It is clear that it is very important to get a balance between the two groups of loops. Gray states that usually, it is reasonable for a period of 3 to 5 years to review the results. Thus, given a large number of variables and their analyses, the experts' opinions, and the review of the literature, the time horizon in this study was 36 months (3 years) so that feedback loops have enough time to function.

3.2. Dynamic hypotheses

A dynamic assumption explains the behavior of a reference status and must be developed according to the purpose of the model. An expert uses a dynamic assumption to extract and test the consequences of feedback loops. He/she then creates diagrams that show the main mechanisms that drive the dynamic behavior of the system. Otherwise, we cannot construct a model without understanding the feedback loops. In general, if there is a good dynamics assumption and a well-known basic mechanism with enough information, we can begin the system with the level and rate equations. Then, we can move on to the next step in the modeling process (Pruyt, 2013; Yang et al., 2021). After done the experts' survey and the literature reviewing, it was found that some criteria were more effective, and others were excluded because of similar effects. Finally, we developed and tested three hypotheses in this study:

- **Hypothesis 1:** By developing a SD model, the optimal values of variables affecting SCA, and flexibility can be estimated.
- **Hypothesis 2:** By developing a SD model, the optimal values of SCA, profitability, and flexibility can be estimated.
- **Hypothesis 3:** By developing a SD model, the effective path to SCA and flexibility can be identified.

3.3. System dynamics model

In this study, we use the SD models and efficient policies to analyze the structure and behavior of a system. For example, using a dynamic system decision-making method can help firms make the right decisions (Pluchinotta et al., 2018), and to identify the factors influencing SCP by considering previous studies in this field. In the next step, with the confirmation of the variables by the experts, the relationship between these variables and the type of their effect on each other was determined. Finally, the causal diagram was plotted using Vensim software. The research variables were extracted using library studies. The variables examined in this model are listed in Table 1.

One important work of basic modeling concepts is to divide the model into some specific areas for analysis and planning. We can select some factors affecting and affected by each other in this area, and the factors that affect but do not significantly affect are outside the system, and other factors that are not significantly affected or not significantly affected are removed from the model.

Table 1. Factors affecting SCP

No.	Variable	Type of variable			References
		Auxiliary	Rate	State	
1	Supplier innovativeness	*			Kim and Chai (2017)
2	Entrepreneurship	*			Malakouti et al. (2017)
3	Participatory management style	*			
4	Suppliers' relationships	*			
5	Resource management effectiveness	*			
6	Dynamic leadership	*			Alzoubi and Yanamandra (2020)
7	Strategic vision	*			
8	Cooperation among members	*			
9	Use of information technology	*			
10	Smartness	*			Nazempour et al. (2018)
11	Confidence	*			
12	Flexibility rate		*		
13	Access	*			
14	Speed in reacting to changes	*			
15	Investments in flexibility and agility	*			Haq et al. (2020), Nikzad et al. (2019)
16	Demand rate		*		
17	Supply rate		*		
18	Delivery time	*			
19	On-time delivery		*		
20	Product quality	*			
21	Service quality	*			Haq et al. (2020)
22	Corporate size	*			Braunscheidel and Suresh (2018)
23	Market sensitivity	*			
24	Cost		*		Kim and Chai (2017)
25	Sales performance		*		
26	SC complexity	*			
27	Total SC inventory			*	Braunscheidel and Suresh (2018)
28	Profitability			*	Alzoubi and Yanamandra (2020)
29	Customer satisfaction			*	
30	Responsiveness			*	

In SD modeling, there are some important elements, such as processes, time, information feedback, and policy latency. In addition, boundary setting is also equally important in SD modeling because the endogenous and exogenous variables are given only by the boundary (Schwaninger & Groesser, 2020). By considering these variables and determining the CAE relationships between them, a stock-flow diagram is plotted as shown in Figure 3.

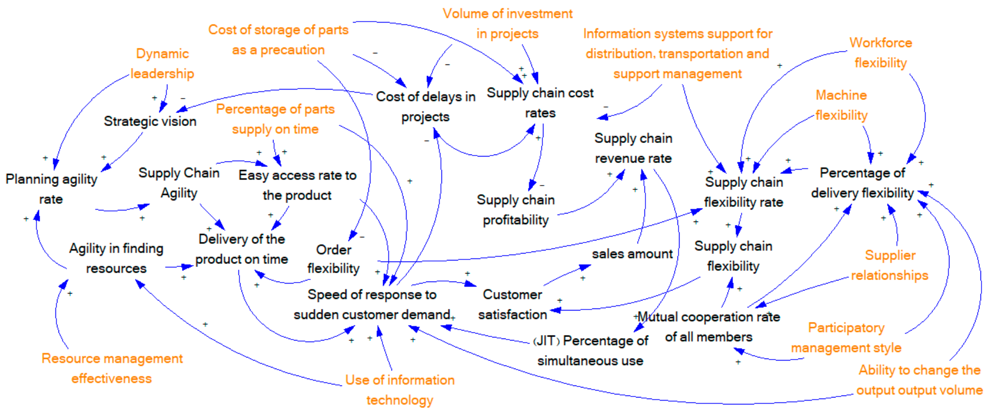

Figure 3. The CAE diagram

Since SCA means the ability to meet changing needs and ultimately deliver goods to the customer, the model shows that SCA has a positive effect on timely product delivery. Besides, other variables such as resource agility in accessing resources due to the availability of resources required to deliver the product and the flexibility of the order to respond to customer demands and deliver the product affect timely product delivery. Furthermore, the higher speed of timely delivery of the product increases the speed of responding to sudden customer demands. On the other hand, the greater use of information technology and the timely supply of materials and products will increase the speed of responding to customer demands, thus reducing the delay in delivering projects and consequently lowering the delay costs. As these costs decrease, the possibility of access to the strategic vision increases due to both the storage of resources and the effective use of time (due to the avoidance of delays). As a result, scheduling agility increases due to effective production scheduling. By increasing the rate of revenues of the chain, more investments can be made in JIT, because on the one hand, the ability to invest increases, and on the other hand, due to the increase in sales figures, the need for JIT also increases. Furthermore, by using this system and considering that this system supports the production sector during production, the ability to respond to sudden demands is increased and as a result, the speed of covering these demands increases. Thus, an increase in the speed of responding to the customer's needs will lead to higher customer satisfaction, which in turn leads to repurchase and ultimately increase sales and increase revenues and profitability. Alternatively, as SCF increases, customer satisfaction increases due to the ability to adapt to environmental conditions and thus the ability to respond to customers. This flexibility comes from variables such as machine flexibility in the production line, labor flexibility in all parts of the SC, and flexibility in delivery in distribution centers. On the other hand, this flexibility requires information system support due to the exposure of the information required for each part of the SC.

Following the analysis of the relationships between these variables and their effect on each other, a CAEM was developed and converted into a state-flow model. Furthermore, the model was simulated under different scenarios to identify the factors affecting SCA and flexibility as one of the goals of this study. The identified factors can be used to develop and adopt strategies to be used in future studies to come up with optimal scenarios.

3.4. Main loops

In this study, a CAEM was developed and transformed into a stock-flow diagram to model and display the relationships between the factors affecting SCA and flexibility. As previous mentioned, the factors in Table 1 were examined and the CAE relationships and the stock-flow diagram for the state, auxiliary, and rate variables were specified. The four important causal loops of the model are shown in Figures 4 to 8. The first loop covers variables such as planning agility rate, SCA, timely product delivery, speed of response to sudden customer demands, project delay costs, and the strategic vision (see Figure 5).

The second loop addressed parameters such as SCPR, SC revenue rate, just in time (JIT) inventory management, speed of response to sudden customer demands, and customer satisfaction (see Figure 6).

The factors considered in the third loop are SCPR, SC revenue rate, just in time (JIT) inventory management, speed of response to sudden customer demands, project delay costs, and SC cost rates (see Figure 7).

The fourth loop addresses the most important factors considered by the firm' managers including SCPR and SC revenue rate (see Figure 8).

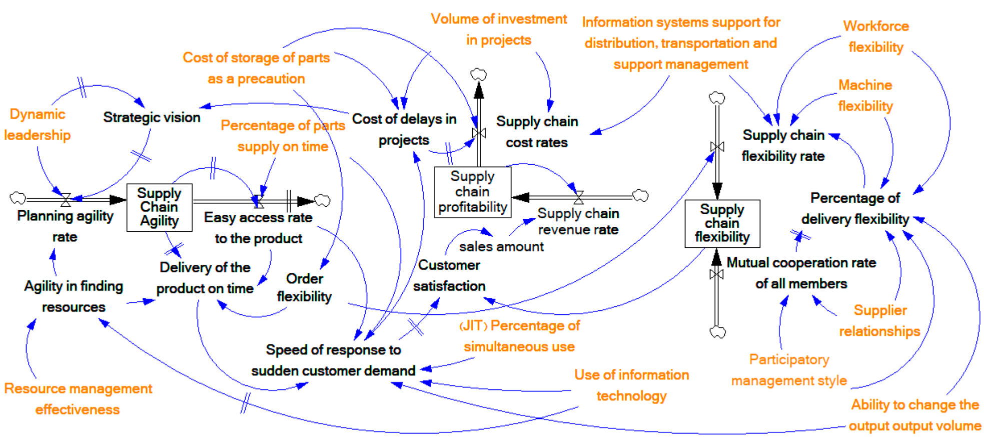

Figure 4. The stock-flow diagram

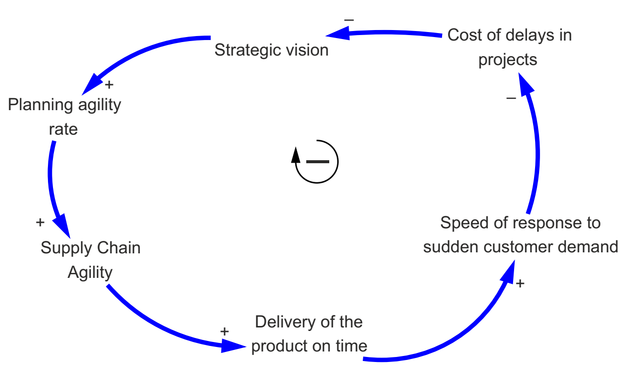

Figure 5. The first loop

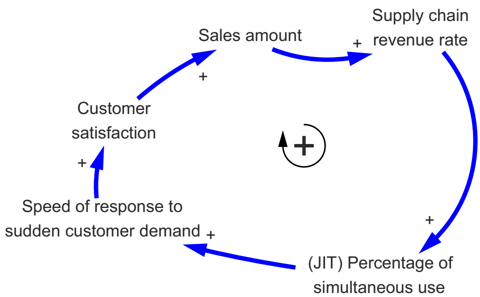

Figure 6. The second loop

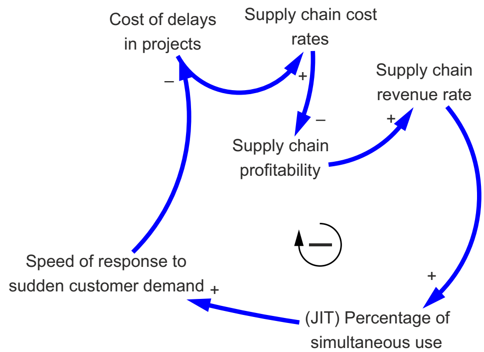

Figure 7. The third loop

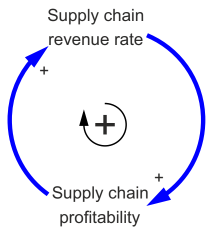

Figure 8. The fourth loop

3.5. Model validation

In order to guarantee the usefulness and accuracy of this model as a policy tool, there is essentially a process to determine the validation of SD models. Firstly, for keeping the validity of a model, one important step is to judge its suitability. This problem depends on the ability of modeling to intelligently perceive the signs of the problem and link them with the causes. The experts' opinion can improve this judgment process. So, Sterman (2000), Qudrat-Ullah et al. (2018), and Schwaninger and Groesser (2020) developed some tests such as Boundary Adequacy Boundary Conditions, Integrity Error, and Behavior Reproduction.

3.5.1. Boundary adequacy test

The boundary adequacy test examines whether important concepts related to the problem have been considered in this model. The model used in this study was developed based on a existing literatures and all important variables were entered into the model based on acknowledging their importance in the literature on sustainable SCP. Accordingly, the necessity and importance of all the variables mentioned in the literature for project-related decisions were examined by the subject-matter experts that the variables incorporated in the model were approved in the literature and also by the experts. To examine whether the behavior of the model shows a significant change after removing the boundary assumptions, the outputs from the model were evaluated after removing some components of the model and changing the model boundary. Figure 9 shows the effect of removing the "planning agility rate" factor which affects SCA, which means we ignore this variable. If we don't consider it, the virtual performance is far from the real situation. So, we must consider all the variables and their interconnections.

Figure 10 shows the effect of removing the "customer satisfaction" factor. This variable affects the profitability of the SC. If we ignore this variable, it also shows a virtual reduction in SCPR. The higher the customer satisfaction, the more purchases occur, and the higher the sales, and thus the higher the profit. Thus, it can be argued that the elimination of this factor is practically equal to zero, and it can be concluded that by eliminating it, both sales and profitability are reduced.

Figure 11 shows the effect of removing the "workforce flexibility" factor. Workforce flexibility has been shown to have a positive effect on SCF and its elimination reduces SCF. Since a large part of a SC is covered by its human resources, the impact of these resources on the chain is not negligible. Accordingly, it can be suggested that workforce flexibility also affects the SCF, and the elimination of this flexibility also reduces the flexibility of the entire chain.

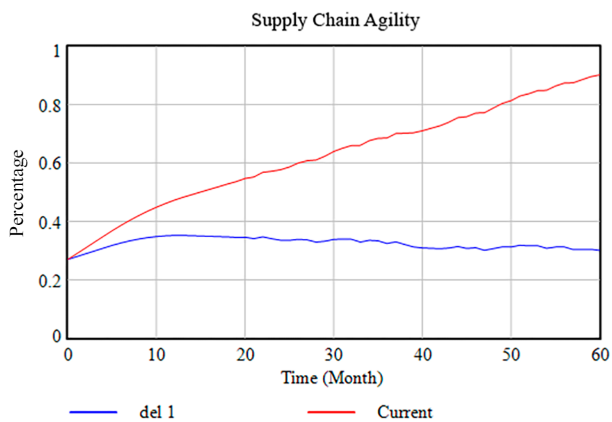

Figure 9. The impact of omitting planning agility rate on SCA

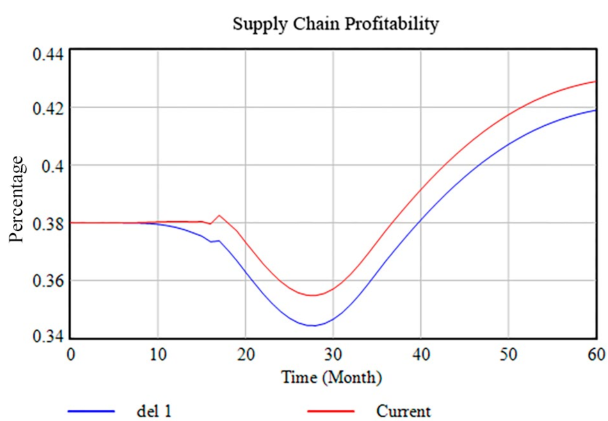

Figure 10. The impact of omitting customer satisfaction on SCPR

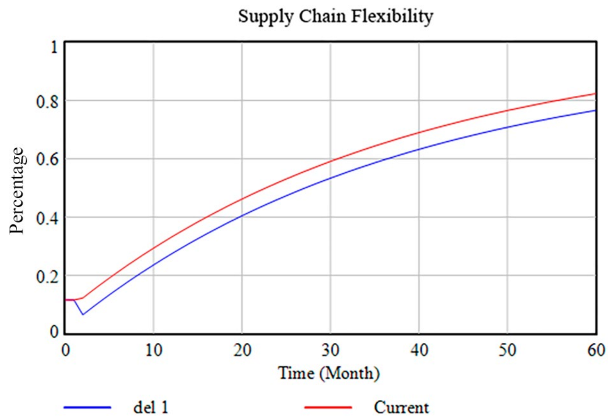

Figure 11. The impact of omitting workforce flexibility on SCF

3.5.2. Boundary condition test

The boundary condition test investigates whether the model performes properly when its inputs are in boundary conditions such as zero or infinity. That is to say, the model must be stable to some extent under boundary conditions. There are two methods to test the boundary conditions: First, to examine all the equations used in the model under the boundary conditions of their variable. Second, it examines the behavior of the model in the scenarios in which the input of the model is in a finite state. In the border adequacy test, the variables at the zero state (the minimum value) were examined.

- **Condition 1:** Dynamic leadership is at its lowest limit (Figure 12).

  If dynamic leadership is at the lowest limit, SCA will reduce. In other words, with the reduction of dynamic leadership, SCA decreases imperceptibly, and this is because the efficiency of an organization depends on its leadership, and if the organization does not have proper leadership and this leadership cannot cope with and adapt to changing conditions, the organization's function is disrupted, negatively affecting its agility.
- **Condition 2:** The speed of responding to sudden customer demands is at its lowest limit (Figure 13).

  If the speed of responding to sudden customer demands tends to decrease, as shown in the figure above, SCPR also decreases. It is very common in business for customers to place orders without any prior plan. However, given the fierce competition between different companies, the winning company is the one that can meet these sudden and unplanned demands and orders as quickly as possible. The greater the coverage of these demands, the profitability of the organization increases for two general reasons: firstly, increasing sales and secondly, increasing customer satisfaction and return. As a result, the more the speed of this response decreases and approaches zero (elimination of the factor), the more the profitability decreases.

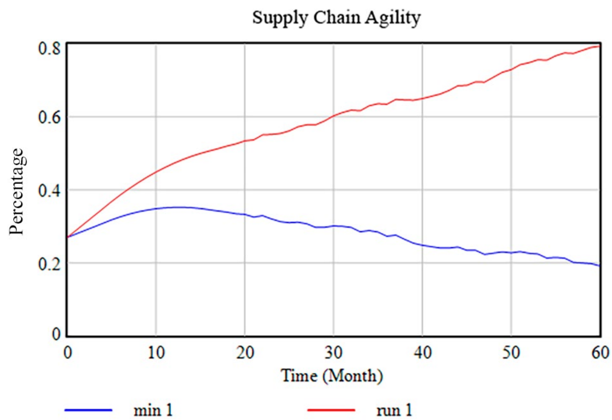

Figure 12. The model behavior when dynamic leadership is in the boundary conditions

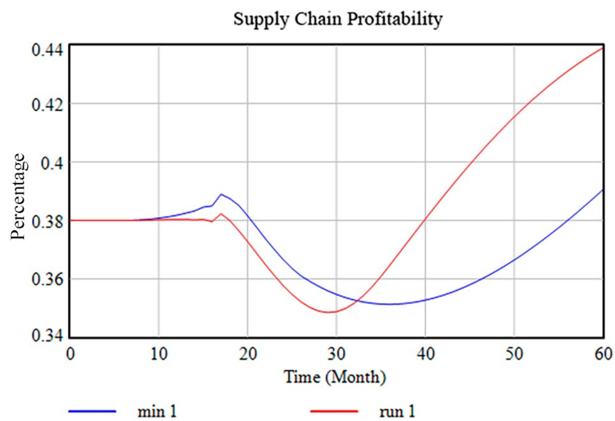

Figure 13. The model behavior when the speed of responding to sudden customer demands is in the boundary conditions

3.5.3. Integrity error test

This test evaluates the sensitivity of the model results to the time range selection. To do this test, the 36-month time horizon for this model was changed to 72 months. There was no change in the behavior of the model and the factors affecting the performance will improve the performance of the model even if controlled (Figure 14).

3.5.4. Behavior reproduction test

This test investigates whether the constructed model is able to reproduce the behavior of the real system. As stated earlier, the developed model in this paper claims to consider the variables affecting the performance of the sustainable SC and can forecast the behavior of the system after identifying the criteria. Figure 15 shows that by controlling the factors affecting performance, performance reduction and SC stability can be prevented. However, we can improve performance by many factors that it takes a longer time to coordinate them.

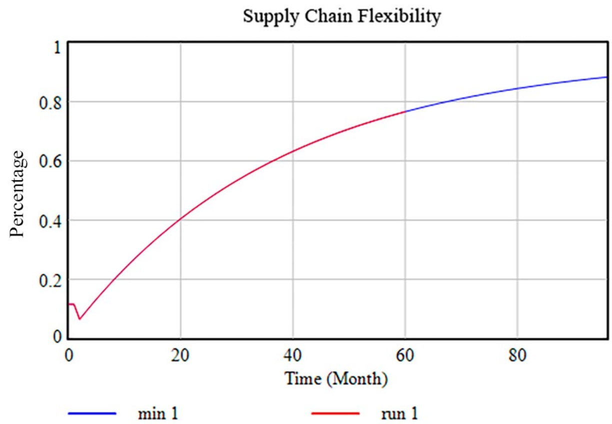

Figure 14. The model outputs in 60 and 96 months

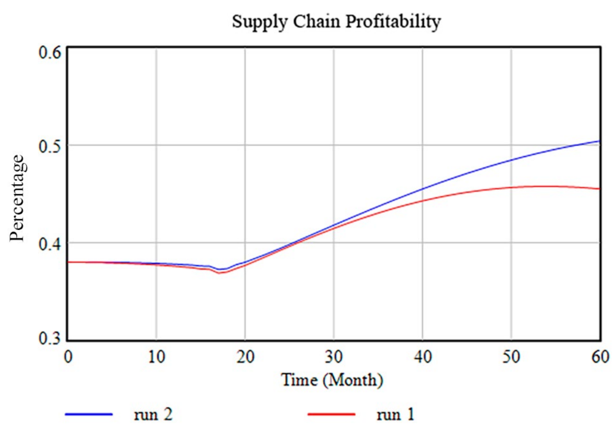

Figure 15. The system behavior after controlling the factors

3.5.5. Error measurement test

To ensure the reliability of the simulation results, in addition to reproducing the model behavior, the error test index was used, and the error rate of the variables was calculated using the methods of calculating the square root error, inequality coefficient, and identifying the roots of the error. The first column in Table 2 shows the percentage of squares error. Based on this index, the smaller the difference between the actual and simulated data, the more reliable are the simulation results can. The second column in the same table shows the inequality coefficient of the model. Calculating the inequality coefficient is also one of the methods for measuring the error rate of simulation data compared to real data. The UT value is between 0 and 1. If UT is zero, it means that the values predicted in the model are equal to the actual value. If UT is equal to one, it means that the performance of the model in question is not satisfactory. The next columns in the table indicate the root cause of the error. Given the importance of error in forecasting, identifying the sources of error and reducing or preventing them can be very effective in increasing the reliability of the model results. Large errors may be due to the high scatter of random data in the model. Accordingly, the roots of the error according to this index are attributed to three factors:

1. **Baseline Error:** When the model outputs are inconsistent with the data, this error occurs which is called systematic error.
2. **Deviation Error:** It occurs when the variances of real and simulation data are very different. The root of this error may also be systematic.
3. **The error of inequality of variances:** When the results of the model and the data are not correlated, this error occurs, which is called non-systematic error.

Under the optimal conditions, the fewer systematic and unsystematic errors, the more efficient the model in simulating the results, but the sum of these errors should be equal to 1. U_m indicates the amount of systematic error and is close to zero or equal to zero under the optimal conditions. U_s is a variance that indicates the simulation standard deviation and actual standard deviation, and it is desirable to have values equal to or close to zero. U_c is a type of covariance that measures the unsystematic error, and it is more desirable with values equal to or close to zero. The results of the above indices are shown in Table 2.

Table 2. The results of error testing based on the simulation data

Variables	Test Index				
	MSPE	UT	Root Cause Analysis		
			U_m	U_s	U_c
Production cost	9.25	0.015	0.003	0.024	0.973
Delivered product per daily	15.33	0.093	0.082	0.061	0.857
Demand	8.25	0.047	0.365	0.133	0.503
Production	15.14	0.129	0.595	0.013	0.392
Greenhouse gas emission	9.32	0.04	0.453	0.016	0.531

3.6. Scenario making

After reviewing the results of analyzing different variables and analyzing their impact on the main variable in the desired time horizons, factors affecting sustainable SCP are identified to enable the decision-maker to choose different scenarios that cover effective indexes to finish effective strategies. In the final step, the different scenarios are developed and tested by determining the different values of the effective indicators. This paves the way to recognize practical strategies. Following the experts' opinions and a review of previous studies in the literatures (e.g., Kim & Chai, 2017; Malakouti et al., 2017; Alzoubi & Yanamandra, 2020; Nazempour et al., 2018), we can determine the factors that have a great effect on the state variable and the rate variables, and by changing the values of these influential indexes, four scenarios were developed and assessed in this study as shown in Figures 16 to 17. These 4 scenarios were designed taking into account the variables that the system is currently able to change.

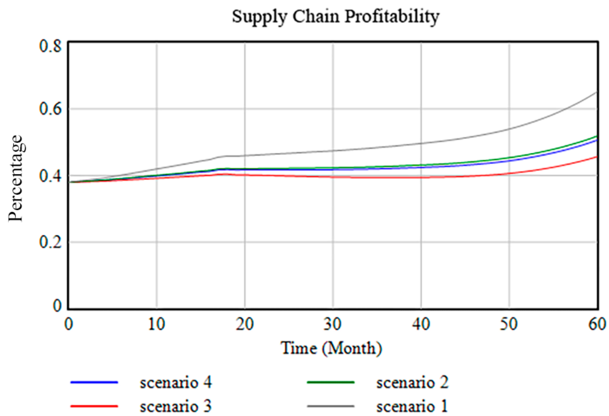

Figure 16. SCPR under different scenarios

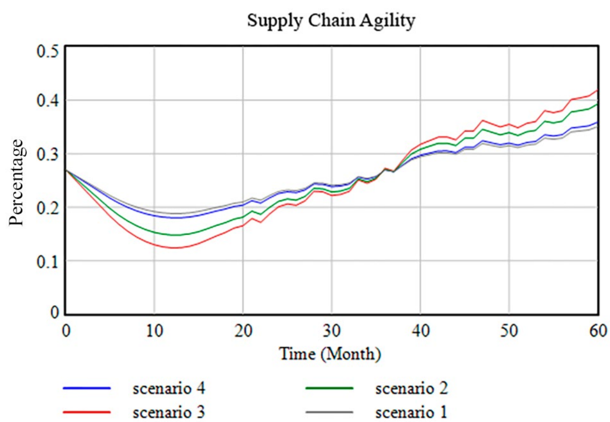

Figure 17. SCA under different scenarios

- **Scenario 1:** The first scenario focuses on the fact that by increasing the ability to change the volume of production output at any time according to environmental conditions, the SC can be directed towards agility. Besides, since this incidence is part of SCF, flexibility increases.
- **Scenario 2:** This scenario tries to increase the flexibility of SC segments. To do this, the two variables of workforce flexibility and machine flexibility increase to examine the impact of the changes on the model and the goals of the model.
- **Scenario 3:** Participatory management is one of the factors that can have a positive effect on AAF (Malakouti et al., 2017), so under this scenario, the value of this variable increases to assess its effect on the goals of the model.
- **Scenario 4:** According to Nazempour et al. (2018), information systems support for distribution, transportation, and support management is a variable that, by disseminating useful information, can make SC members more flexible and accelerate its speed in responding to changes. Thus, in this scenario, the effect of changing this variable on the target variables was evaluated.

Considering these scenarios, the model was run again and the changes of state variables in these four scenarios were plotted in terms of the research variables including SCPR, SCA, and SCF (Figures 16–18).

Figure 15 shows the simulation results under the four scenarios. As can be seen, the first scenario yields the best outcomes for the SCPR.

Figure 16 shows the simulation results for SCA under the four scenarios. As can be seen, the third scenario yields the best outcomes in terms the SCA.

Figure 18 shows the simulation results for SCF under the four scenarios. As can be seen, the third scenario yields the best outcomes in terms the SCF: as shown in Figure 14, and given that the main goal in SCs is to achieve higher profitability rather than higher AAF, the first scenario generally indicates that when the ability to change the production output increases, the best results are obtained in this system and it is possible to determine optimal states for the variables affecting the model. These variables were determined and assessed according to the different conditions of suppliers and manufacturers, distributors, inventory, customer satisfaction and various types of SC costs through reviewing different studies in the literature and surveying subject-matter experts.

The results indicated that AAF alone and absolutely cannot lead to higher profitability. Besides, to increase profitability, AAF should not be raised to the highest level, and the highest profitability is gained when they are equal to 35.06% and 45.8%, respectively. These results indicate that spending on AAF is economically profitable to some extent and investing in these two factors beyond a given limit is not profitable. To achieve optimal conditions, researchers must define strategies to recognize factors affecting the ability to change the volume of production output. Strategies such as improving IT systems, improving supplier relationships, determining the optimal amount of inventory to prevent shortages, effective resource management, scheduling timely delivery, effective planning for collaborative management among chain members, proper investment in projects can help achieve the optimal conditions for improving SCPR.

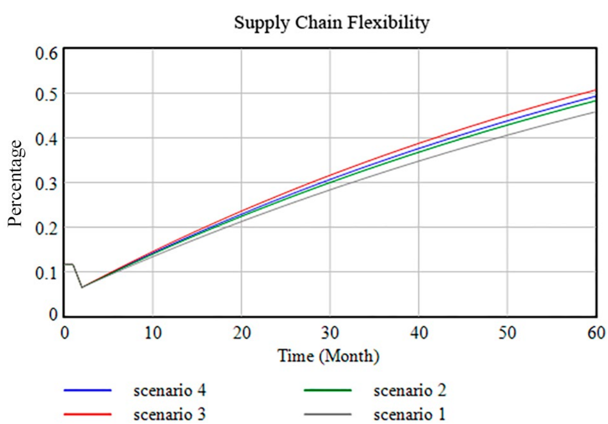

Figure 18. SCF under different scenarios

Conclusions

The present study showed that solving complex and multidisciplinary problems of the current world, especially the study of sustainable SCP requires an effective systematic method because solving these problems using current mathematical and linear methods are associated with limitations and problems and thus these models are not able to provide completely real results. For this purpose, one of the effective methods is to use SD. It is clear that changes do not occur all at once and they follow a dynamic process. Thus, changes occur through the interaction of different factors. Since understanding and controlling dynamic phenomena is not an easy task, it leads to an increase in their complexity, which makes it very difficult to identify the right direction for change. Hence, one of the major challenges for organizations is to identify the right change and take action to create it.

The present study focused on identifying factors affecting SCP, their interrelationships, and how they affect the whole system. A model was developed using these variables to simulate SCP using Vensim software. Given that this study focused on a real organization and the accessibility of real data on the behavior of these variables in the organization, the simulated behaviors were compared with reality and the results were tested with possible methods. Considering the high degree of compatibility of the simulated model performance to the actual chain performance, it can be suggested that the identified variables were to a large extent the main variables affecting the behavior of the chain performance. Since SCA means the ability to respond to changing needs and timely delivery of products to customers, the assessment of the first loop showed that SCA has a positive effect on timely product delivery and thus increases the speed of responding to sudden customer demands. As this speed increases, the delays in the projects decreases, and consequently the cost of these delays also decreases. As these costs decrease, the possibility of access to the strategic vision increases due to both the storage of resources and the effective use of time (due to the avoidance of delays). Finally, as the SC approaches its strategic vision its agility increases as the result of fulfilling the devised plans. Furthermore, the assessment of the second loop indicated that by increasing the rate of revenues of the chain, more investments can be made in JIT, because on the one hand, the ability to invest increases, and on the other hand, due to the increase in sales figures, the need for JIT also increases. Furthermore, by using this system and considering that this system supports the production line, the ability to respond to sudden demands is increased and as a result, the speed of covering these demands increases. Thus, an increase in the speed of responding to the customer's needs will lead to higher customer satisfaction, which in turn leads to repurchase and ultimately increases sales and enhances revenues and profitability.

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