Archives of Razi Institute, Vol. 77, No. 3 (2022) 1291-1302

DOI: 10.22092/ARI.2022.357504.2049

Original Article

Investigation of the Behavioral Model of Suppliers of Raw Materials for Biological Products with a System Dynamics Approach (Case study: Razi Vaccine and Serum Research Institute)

Seraji, S[1], Mehrmanesh, H[1 *], Kasraee, A. R[1]

1. *Department of Industrial Management, Central Tehran Branch, Islamic Azad University, Tehran, Iran*

Received 10 January 2022; Accepted 8 February 2022
Corresponding Author: has.mehrmanesh@iauctb.ac.ir

Abstract

The dynamic and variable environment of today's business has created a highly competitive atmosphere; n order for organizations to survive and succeed, they need to provide new and efficient methods in all aspects of their work. Therefore, supply chain management, as one of the effective factors in the quality of performance of the organization, has been an especial area of attention and since the quality of the final product is strongly dependent on the raw materials of the product and the efficiency of the supplier, the suppliers' proper performance will guarantee the stability of the supply chain. One of the major challenges for managers in a dynamic and uncertain environment is identifying supplier evaluation indicators, and this article tries to provide a reliable approach to this important challenge. Therefore, the main purpose of this paper is to investigate of behavioral model of suppliers of raw materials for biological products with a system dynamics approach. Accordingly, the reliability and accuracy of the proposed model has been evaluated by several statistical tests. Finally, the performance of this model is shown in the supply chain of Razi Vaccine and Serum Research Institute. The results obtained both in the tests and in the case study, all indicate the ability, reliability and high accuracy of the model in suppliers' evaluation.

Keywords: system dynamics approach, biological product supply chain, supplier evaluation, cause and effect diagram, flow-state diagram

1. Introduction

Today, the achievement of sustainable competitive advantage is the goal of many companies and organizations. This great goal has attracted a significant deal of attention in recent decades in organizations regarding their strategic planning. Much of this attention has been focused on supply chain management, which has found a special and important place in the strategic management literature. To prove this claim, we can refer to successful companies in global markets that have been able to gain many competitive advantages by paying close attention to their supplier network and giving important roles to these suppliers in strategic planning (1). Since supply chain management, through its strategic vision, helps an organization achieve strategic goals, the proper performance of suppliers can make organizations successful in achieving their goals. One of the challenges of organizations in the last century is to employ the right suppliers and develop their performance (2).

Many active companies acknowledge that today's competition is focused on the supply chain whose management will be the most important source of competitive advantage (3). Therefore, the essential role of suppliers in improving the supply chain has made the issue of identifying criteria as well as ranking and selecting the suppliers particularly important (4, 5). The more organizations rely on suppliers, the more damaging the direct and indirect consequences of incorrect decision making will be. Globalization of business and the increasing spread of the internet have increased the methods and modes of supplier selection. Achievment of customer satisfaction and fulfilment of customer needs and priorities require rapid and appropriate selection of suppliers (6). New organizational structures have involved more people in decision-making to select suppliers; therefore, the importance and position of decision-making has increased (7). The complexity and importance of decision-making in selecting suppliers, indicate the need for a clear and transparent method. Wrong choice of supplier can disrupt the financial and technical position of a supply chain (8).

Evaluation, ranking and selecting the right supply chain suppliers is not only considered an important factor in profit-making of organizations and achievment of their goals in today's competitive environment, but also an effective factor in product quality, service delivery, and business activities. The most important goal of supplier selection is to identify the suppliers who consistently have the highest potential to meet the company's needs at an acceptable cost (9). Therefore, selection of the right supplier in supply chain management is a challenging issue. One of the most important supply chains in industries is the biological industry (10).

Given the importance of this issue and the fact that in recent years biotechnology has faced many changes (e.g., the globalization of markets, changes in technology, changes in customer needs, and shortening the life cycle of products) and also the key role of suppliers in the improvement of this chain, we decided to perform this research. The present study aimed to examine the issue of supplier selection by identifying the most important criteria in dynamic environmental conditions.

Strategic cooperation with suppliers to provide goods with the desired quality and reduced delivery time in Razi institute projects is a priority. Therefore, one of the goals of the institute in a competitive environment is to provide quality goods in a timely manner and at a reasonable cost with regard to other performance indicators. Due to this fact, the selection of suppliers has a significant impact on the achievment of these goals and this process is very important in the upcoming successful projects of Razi institute.

In the projects of Razi institute, the process of selecting suppliers should be sensitive and accurate due to the high cost and sensitivity of the required equipment and materials, the need for the necessary standards and safety, and the importance of their time of arrival in the institute because of the losses caused by daily delays in the production and distribution in the country. Provision of a complete dynamic system that is able to automatically receive, store, and infer the characteristics of suppliers from the environment to automatically and intelligently adapt the behavior of variables in all its managerial and operational aspects to cope with the changes in the environment can be considered as a long-term process.

Despite much research on supplier evaluation and selection, there is still the lack of a dynamic systems approach in various areas. In Razi institute, due to the high volume of purchases and supplies and their sensitivity, as well as the uncertainty in the parameters and variables, the evaluation and selection of suppliers based on a model of system dynamics is very important and vital. Therefore, in this research, dynamic system simulation has been used for the investigation of behavioral model of suppliers of raw materials for biological products in Razi institute.

The structure of the model is designed in such a way that competition between suppliers is considered. Hence, if any of the providers see their interests at risk, they may make changes and improve their performance. According to the four suppliers and their related parameters, which include 16 criteria, compared to suppliers in different periods, the results of the dynamic system model lead to ranking and selecting suppliers. After simulation, the validity of the model was checked with several tests, including boundary adequacy test and integrity error test. Finally, the results obtained from the dynamic system model were confirmed.

2. Materials and Methods

This research was applied in terms of purpose and descriptive in terms of data collection. Moreover, among the methods of descriptive research, it was a conducting one as the required data were collected using the cross-sectional method. By presenting a model of system dynamics, it was tried to evaluate the suppliers of bio-industry and in order to select them, we examined the necessary variables and analyzed their behaviors in time intervals. Therefore, the data were collected through interviews and localized researcher-made questionnaire.

2.1. Data Analysis Method

In this paper, the systems dynamics approach is used to simulate the behavior of influential variables in the evaluation of Razi Institute suppliers. Causal and mathematical relationships between the main and secondary variables of supplier evaluation were identified in the form of two cause and effect diagrams and flow status diagrams. VENSM Vensim_PLE_7.3.5_x86 software was implemented and the model was validated and tested. Finally, various strategies in the field of evaluation and selection of suppliers in the application model and its effects on the cost and revenue of Razi Institute in this system in the long run were simulated and the best supplier was selected in the defined time period.

2.2. Dynamic System Modeling

The modeling process is not a very clear process and one should not expect all the steps to be clear and lead us to the conclusion. Each modeler has different approaches; however, all successful modelers follow a regular process that includes the following activities:

1) Framing the problem
2) Creating a dynamic hypothesis about the causes of the problem
3) Formulation of a simulation model to test a dynamic hypothesis
4) Model test
5) Design and evaluation of policies for improvement (11)

The main art of modeling with systems dynamics is to discover and introduce feedback processes that help identify system structure defects rather than blaming those who make them. Figure 1 shows the modeling process in more detail.

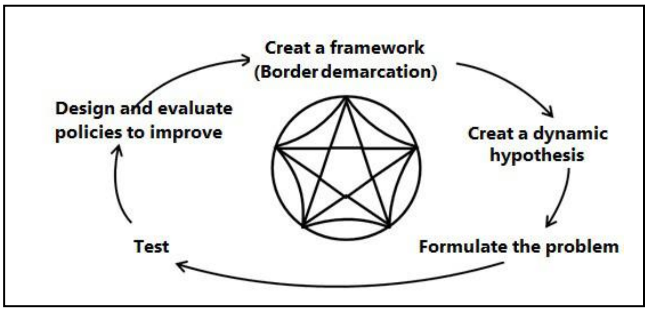


Figure 1. Main steps of the modeling process

2.2.1. System Boundaries

Each system has a limit that separates it from its surroundings and at the same time connects it to the environment. As a matter of fact, the boundaries of the system are points beyond which the specific features of the system are no longer recognizable. Perhaps if we consider the border as larger, we will understand the facts in a much more clear and better way. However, it must be kept in mind that sometimes enlarging the boundaries of the system creates complications that can make it difficult to solve the problem. The model boundary is not predetermined and is determined by the modeler (12).

In this research, different indicators were considered for the supplier evaluation model, such as product type and supplier services. Hence, the model boundary shown in table 1 briefly identifies the model range by identification and categorization of the endogenous and exogenous variables of each level. An exogenous variable is a variable whose value is determined outside of the model and imposed on the model and an exogenous change refers to a change in an exogenous variable. In contrast, an endogenous variable is a variable whose value is determined by the model itself and an endogenous change means a change in an endogenous variable in response to an exogenous change imposed on the model.

Table 1. System boundary

Level	Indicator	Variable type
Product	Price	Exogenous
	Quality	Endogenous
	Variety of production line	Exogenous
Service	Reliability of product delivery	Endogenous
	Supplier obligations	Endogenous
	Registered business experiences	Exogenous
Risk	Trade restrictions	Exogenous
Supplier background	Perception and acceptance of risk	Exogenous
	Documents	Exogenous
Cost	Ability to reduce costs	Endogenous

As can be seen in table 1, the model boundary is defined in five levels of product, service, risk, supplier background, and cost, taking into account various factors, such as price, quality, and supplier obligations, while other factors are excluded.

After determination of the purpose and boundaries of the model, the factors affecting the key variables of the problem must be identified. What variables are involved in evaluating providers? What is the position and ranking of each supplier, compared to its other competitors? What is the status of each supplier in the short and long term? when it comes to making decisions or changes in this area, we must know how changes will affect the evaluation process in the long or short term.

2.2.2. Modeling

Feedback is a process in which a variable, in a series of cause-and-effect relationships, affects other variables in a way that it eventually increases or decreases by affecting itself. In this regard, there are two types of cause and effect relationships (13):

Positive cause-and-effect relationship (+): Changing the cause in one direction causes the effect to change in the same direction (Figure 2a).

Negative cause-and-effect relationship (-): Changing the cause in one direction causes the effect to change in the opposite direction (Figure 2b).

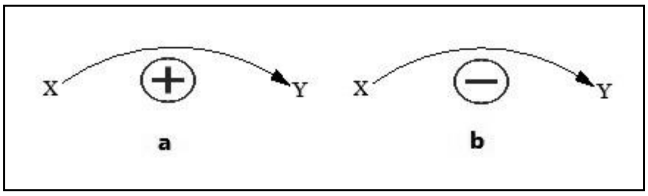


Figure 2. Positive and negative causal relationships

In this regard, the connections between the components of the system are not linear and are in the form of cause and effect loops. There are two types of loops, namely positive loop (amplifier/reinforce) and negative loop (balancer). To determine if the loop is negative or positive, the effects of a small change in one of the variables within the loop is traced. If the feedback exacerbates the initial change, the loop is positive, and if it opposes it, the loop is negative. The symbols used for positive and negative circles are as shown in figure 3.

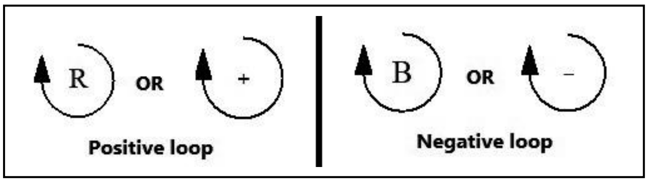


Figure 3. Feedback loops

2.2.3. Causal Patterns

Drawing loops and conceptual relationships between variables is one of the most important steps in building dynamic system models. In this section, we provide charts related to supplier evaluations. First, it should be noted that the performance of each supplier and its ability to meet the demands of the organization are determined and evaluated by different factors (13). Moreover, the interaction between these indicators can reduce or increase each one of them. Furthermore, it is obvious that each of the suppliers does not act individually and is competing with the others by trying to increase their success in meeting the demand of organizations. Now the important point is which supplier is selected to meet the demand of the organization and how it will affect the performance of other suppliers.

In this section, after examining the system boundary and determining the desired factors, the cause and effect patterns are discussed by considering two suppliers. If two suppliers are initially evaluated by the experts of the organizations and their performances are ranked and scored by different indicators, it is obvious that the purchase demand from the supplier with a higher score will increase. This will create competition for suppliers who offer the same or similar products. Therefore, the two companies (suppliers A and B) are competing for more market share.

Accordingly, if the performance of supplier A improves, its demand increases and supplier B is stimulated to compete. With the increase of competition, supplier B will try to improve its performance level which leads to an increase in its demand as well as the competition of the supplier A. As the competition increases, the level of performance of the supplier A increases again. The representation of part of the amplifier loop for the four suppliers is shown in figure 4. If the performance level of a supplier improves and causes the organization to place its orders to it, the amount of revenue of that supplier will increase and lead to its greater profitability.

As the profit increases, the company will increase the quality of its product which will improve the supplier performance. Figure 5 shows this part of the model.

By improving the product quality, the supplier will deliver more reliable products to the applicants. This will enable the supplier to better perform its obligations to the organization and improve its level of performance by increasing the credibility of its collection. This part of the model is shown in figure 6.

As mentioned before, to simplify the cause-and-effect model, in different sections, the model is shown for one or two suppliers, and in cases where the suppliers are similar in terms of the factors under consideration, the other suppliers can also be added to the examination. However, it should be noted that the general model of this research is intended to evaluate four suppliers that are shown in figure 7 as an overview of the related cause-and-effect model.

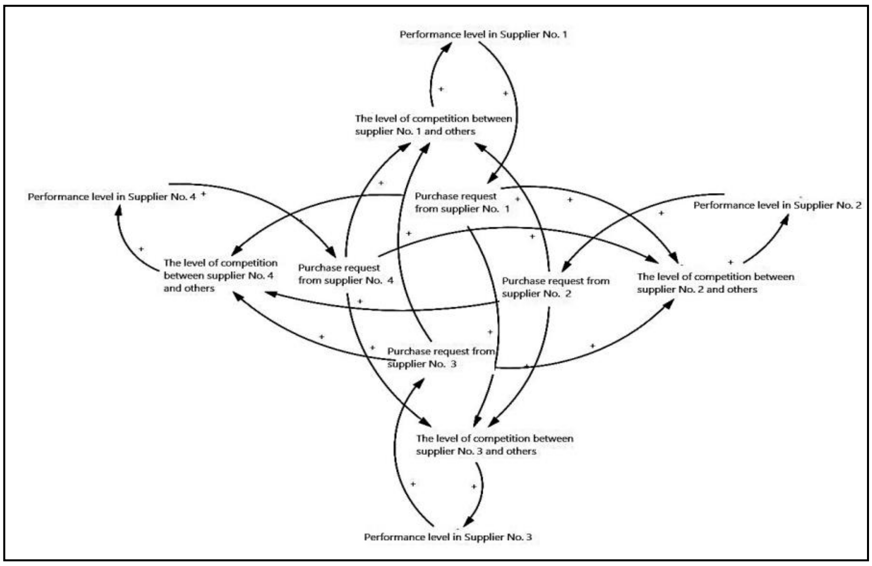


Figure 4. Reinforcing loop in the model (with four suppliers)

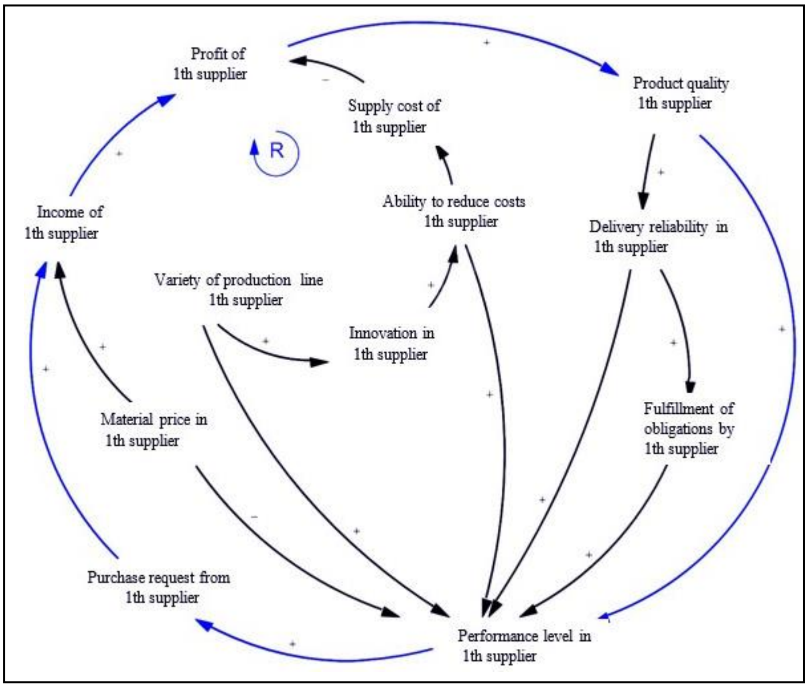


Figure 5. Cause and effect loop that reinforces the profit of the supplier

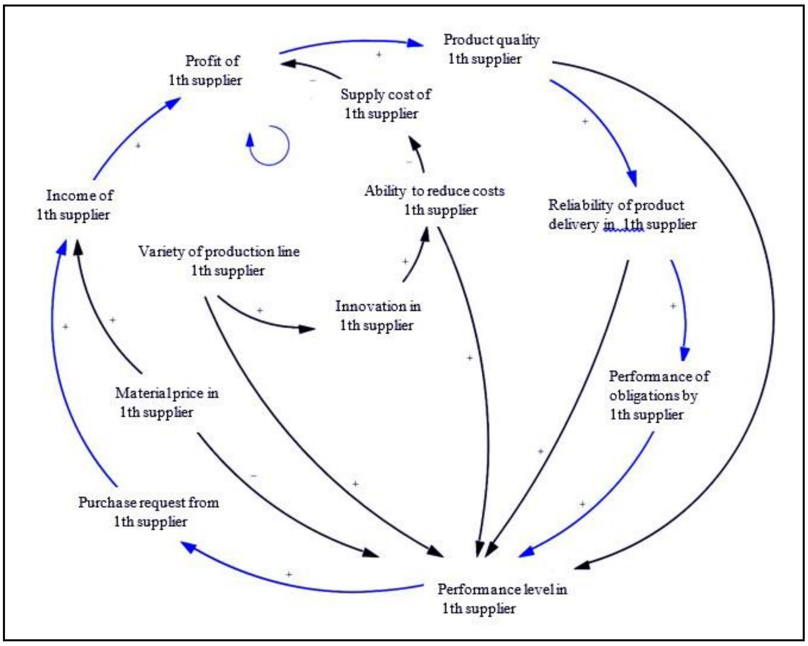


Figure 6. Cause and effect loop related to supplier commitments

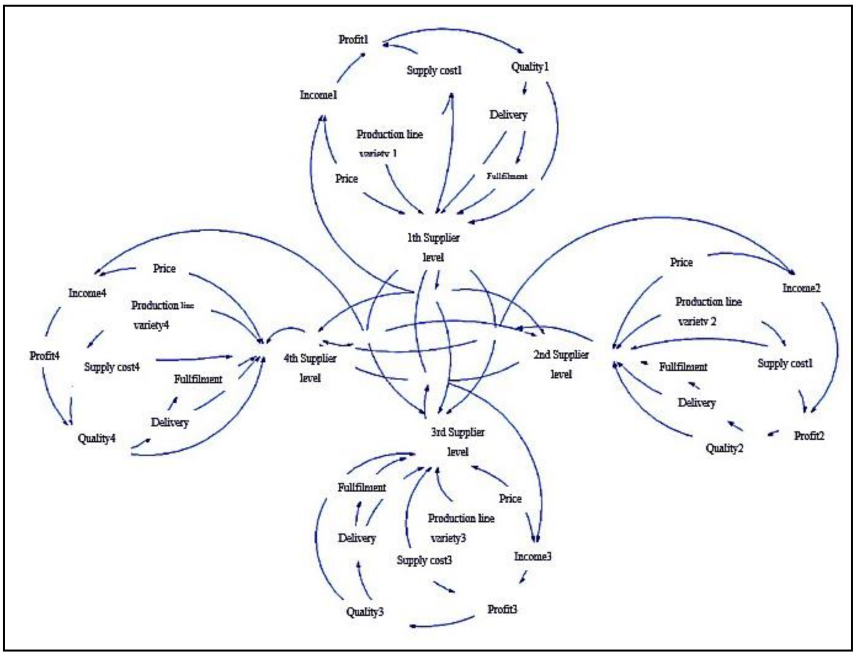


Figure 7. Complete cause and effect diagram

2.2.4. Mode Flow Chart

In the previous section, the causal model was used to show the interdependencies and feedback processes in the supplier evaluation system. However, due to the limitations of these diagrams (e.g. the inability to display the variable structure and flow structure of systems) there is a need to implement another form of diagram called Stock-Flow diagram. Stock-Flow diagram is composed of different elements that are discussed below:

2.2.4.1. Stock Variable

Stock variables, such as level, accumulation, inventory, storage, or warehouse, are variables only change over time, and their values at any time depend on the value of this variable and other variables in previous times. These variables are represented by a rectangle. The value of each state variable is equal to the addition of the inflow to it minus the outflow of it. In general, its mathematical concept is equal to:

$$\text{Stock}\,.(t) = \int_0^t (\text{inflow}(t) - \text{outflow}(t)) + \text{Stock}(t_0)$$

2.2.4.2. Flow Variable

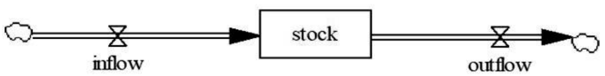
These variables describe the accumulation rate of the system and reflect changes in accumulation variables over time. These variables are the streams that enter or exit an accumulation variable, and therefore, the decision made in the form of flow variables over time affects the accumulation variables or our information from the system. Input streams are represented by an arrow with its head pointing towards the state variable, and output currents are shown with an arrow whose head is facing the outside of the state variable. In the following, we show the relevant flow mode diagrams by introducing the available variables. Table 2 shows the variables and their types.

$$\frac{d(\text{stock}(t))}{dt} = \text{inflow}(t) - \text{outflow}(t)$$

Table 2. Stock-flow variables and their types

Row	Variable	Type	Row	Variable	Type
1	Performance level of supplier 1,2,3,4	Stock	10	Business experience of supplier 1,2,3,4	Exogenous
2	Performance increase rate of supplier 1,2,3,4	Flow	11	Acceptance rate of risk in supplier 1,2,3,4	Exogenous
3	Request to purchase from supplier 1,2,3,4	Endogenous	12	Documentation of Supplier 1,2,3,4	Exogenous
4	Competitiveness of supplier 1,2,3,4 with others	Endogenous	13	Production line flexibility in supplier 1,2,3,4	Exogenous
5	Material price of supplier 1,2,3,4	Exogenous	14	Business restrictions of supplier 1,2,3,4	Exogenous
6	The income of supplier 1,2,3,4	Endogenous	15	The supplying cost for supplier 1,2,3,4	Endogenous
7	Ability to reduce costs by supplier 1,2,3,4	Endogenous	16	The obligations fulfillment level by supplier 1,2,3,4	Endogenous
8	Level of innovation in supplier 1,2,3,4	Endogenous	17	Delivery reliability of supplier 1,2,3,4	Endogenous
9	Profit of supplier 1,2,3,4	Endogenous	18	Material quality of supplier 1,2,3,4	Endogenous

Figure 8 shows an overview of a state-flow diagram.



As can be seen in table 2, when the organization evaluates four suppliers, the model has four state and four flow variables while the other variables are auxiliary ones.

Figure 9 shows the corresponding diagram.

2.3. Model Validation

In this study, after simulation, the validity of the created model was examined by several tests, which are described in the continuation of these tests and the results of their application for the model will be stated.

2.3.1. Boundary Adequacy Test

This test checks that important problem-related concepts are considered within the model. In this research, the proposed model and its key variables are identified and entered into the model based on a review of the literature and opinions of experts in a way that it can be used for decision-makings related to the problem. Regarding the question whether the behavior of the model shows a significant change after removing the hypothetic boundaries or not, the results of the proposed model were examined after removing parts of the model and changing the model boundary. Figures 10, 11, 12, and 13 show diagrams of the effect of removing the "purchase demand" variable.

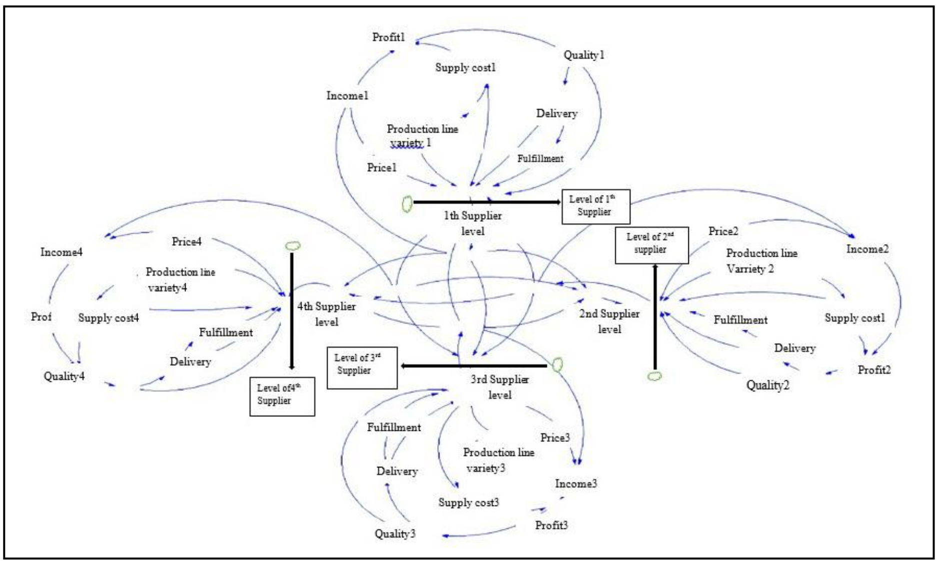


Figure 8. Stock-Flow Diagram

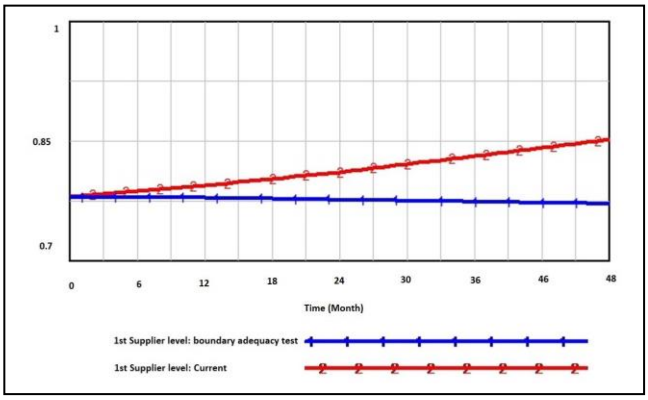


Figure 9. Sensitivity analysis of the model to the purchase request variable in 1st supplier

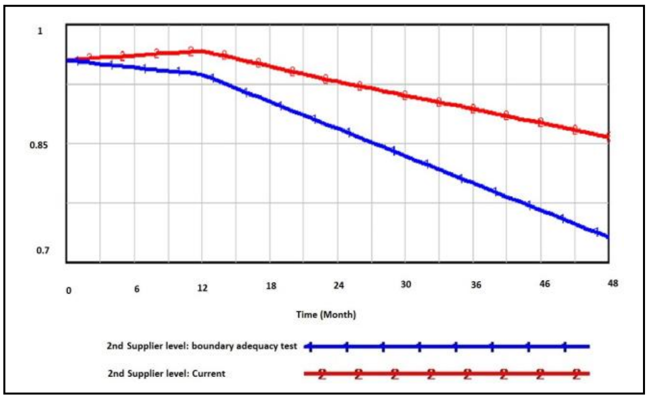


Figure 10. Sensitivity analysis of the model to the purchase request variable in 2nd supplier

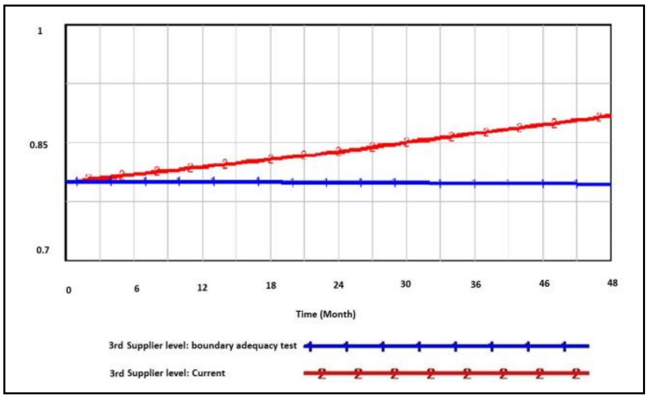


Figure 11. Sensitivity analysis of the model to the purchase request variable in 3rd supplier

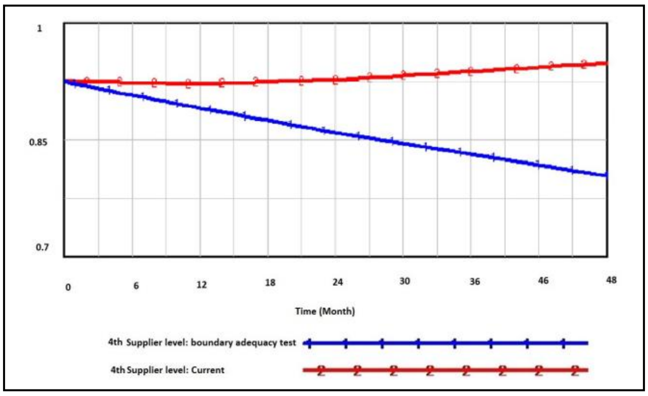


Figure 12. Sensitivity analysis of the model to the purchase request variable in 4th supplier

The red chart is for a situation where there is a demand for supply from the number one supplier. In the blue diagram, it is assumed that this variable is deleted. As can be seen in the blue diagram, in the absence of demand from the organization, as expected, the supplier level will not grow much since its revenue and profit will decrease, and remain at the same level as before. Moreover, the inventory of the producer after the addition of the quantity produced to the amount of the initial inventory remains at the same level and due to the lack of demand, there will be no sending to other levels of the supply chain.

2.3.2. Integration Error Test

This test examines how sensitive the model is to period selection. For this purpose, the 48-month period of the model was changed to 60 months. As can be seen in figure 14, the trend of model for the performance level of the number one supplier in the new time period has not changed, and the model will continue to move in the same way over the long run. The integrity error test for the other three suppliers is given in figures 15 and 16.

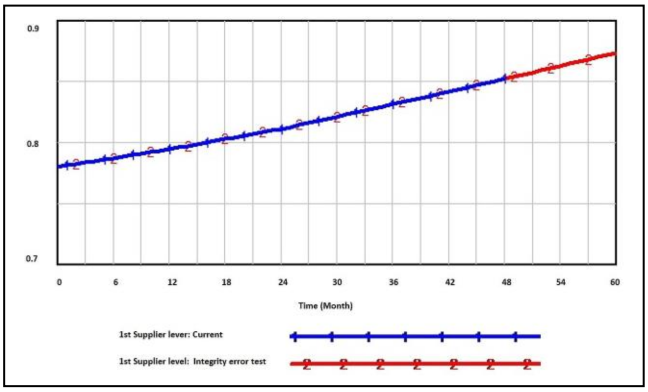


Figure 13. Sensitivity analysis of the model of time variable in 1st supplier

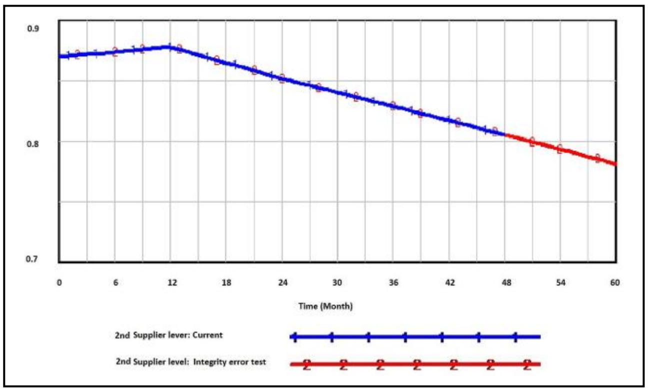


Figure 14. Sensitivity analysis of the model of time variable in 2nd supplier

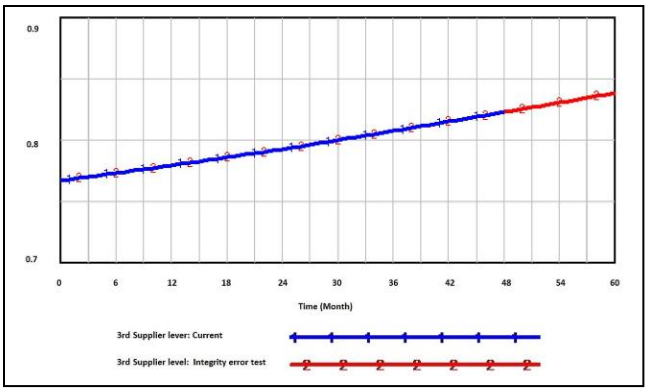


Figure 15. Sensitivity analysis of the model of time variable in 3rd supplier

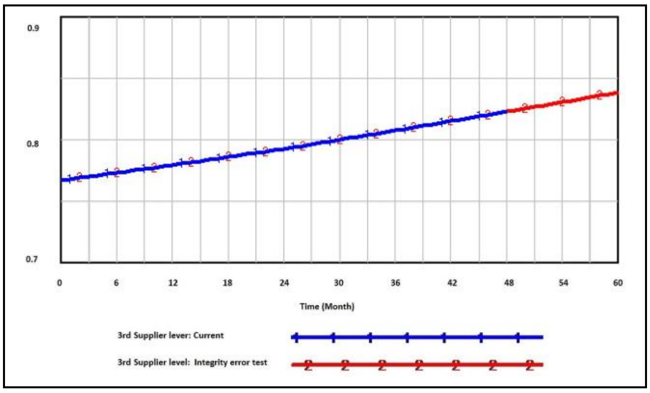


Figure 16. Sensitivity analysis of the model of time variable 4th supplier

3. Results

Given the growing importance of suppliers in the profitability and quality assurance of supply chain organizations, their proper selection can ensure the stability of the relationship between the organization and the supplier. For this reason, we used the dynamic system approach to simulate the behavioral model of the suppliers in the VENSM software (Vensim_PLE_7.3.5_x86) to have a good understanding of their behavior and how each of the suppliers change and evolve over time, taking into account dynamic parameters and different factors. The competition between suppliers is considered in the design of the structure of the model; accordingly, if any of the suppliers are at risk, they start to change and improve their performance.

Suppliers were selected and evaluated based on the most important criteria extracted from the opinions of experts and by means of questionnaires and interviews. However, using the dynamic approach of the system, the competitive behaviors of suppliers were identified and then they were prioritized. In addition, if changes are made in any of the indicators, appropriate decisions can be made. For this purpose, the scores of each index were determined and recorded separately for each supplier at the end of two 12-month periods. According to these scores and the feedback behaviors in the evaluation system, their performance was simulated for subsequent periods. It should be noted that the performance of each supplier was evaluated based on a scale ranging from zero to one. Figure 17 shows the results of this simulation.

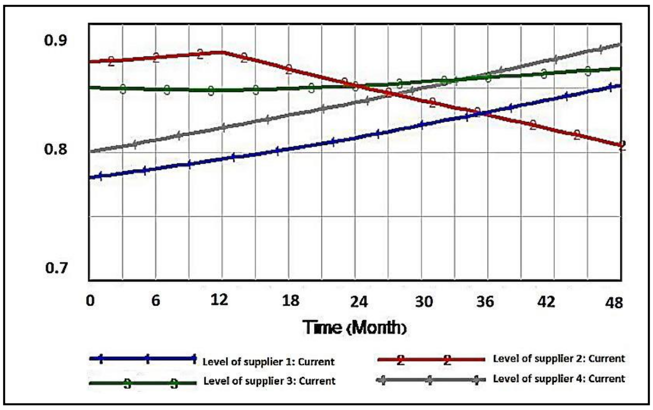


Figure 17. Performance level of suppliers

4. Discussion

In the current competitive environment, what leads to a competitive advantage is the strategic focus of companies on supply chain management. Therefore, with the essential role of suppliers in improving the supply chain, identifying criteria and ranking and selecting the most appropriate supplier is also of particular importance (14). Extensive studies in this field in various industries have been conducted by researchers such as de Boer, Labro (15), (16), but few studies have been able to address the importance of the time parameter and environmental changes over time (17, 18).

The present study provides a suitable method for investigating the behavior of suppliers in a dynamic environment and its impact on the level of performance of other competitors and thus selecting the most appropriate supplier. According to the obtained results, it is suggested that the evaluation of suppliers using the system dynamics method be considered as it can be a good way to examine the relationship between suppliers and their dynamic behaviors as well as the problems related to the selection of an inappropriate supplier and eliminate its costs.

Finally, suggestions can be made for future studies and further actions, including: conducting research for other departments and subdivisions active in those departments in order to increase generalizability and key outcomes. Paying attention to the political and economic factors governing the Razi Institute, such as sanctions, international crises and the current Covid-19 epidemic, which has also led to a lack of direct contact with foreign suppliers. Geographical considerations (native or non-native) related to suppliers should be considered. The impact of government policies and its impact on the performance of organizations, especially government organizations should be analyzed with a dynamic system approach.

Authors' Contribution

Study concept and design: H. M. and S. S.
Acquisition of data: S. S.
Analysis and interpretation of data: S. S.
Drafting of the manuscript: S. S.
Critical revision of the manuscript for important intellectual content: H. M. and A. R. K.
Statistical analysis: S. S.
Administrative, technical, and material support: H. M. and A. R. K.

Conflict of Interest

The authors declare that they have no conflict of interest.

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