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A System Dynamics Model to Evaluate the LARG Supply Chain Elements in the Automotive Industry

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ABSTRACT

The automotive industry is highly competitive, requiring robust supply chains to secure a strategic advantage. This study uses the Lean, Agile, Resilient, and Green (LARG) paradigms to evaluate supply chain performance in the automotive sector. This article developed a comprehensive system dynamics model to analyze these paradigms, incorporating key elements and their interactions within the supply chain. The model simulated eight scenarios to assess the impact of different strategies on supply chain performance. Research findings highlight that enhancing supply chain efficiency leads to the most significant increase in income, underscoring the importance of optimizing processes and reducing costs. Improving process flexibility emerged as the second most impactful strategy, enabling quicker adaptation to market changes and customer demands. Optimizing the flow of value and added value created also proved crucial, streamlining processes and reducing waste to enhance profitability. This research provides actionable insights for automotive industry stakeholders. Companies can substantially improve supply chain performance by focusing on efficiency, flexibility, and value flow. The study emphasizes the practical application of the LARG paradigms, offering a holistic framework for supply chain management in the automotive sector. In summary, the research system dynamics model demonstrates the critical role of LARG elements in driving supply chain success. This approach enables automotive companies to strategically enhance their supply chains, ensuring competitiveness in a dynamic market environment. The results offer valuable guidance for implementing effective supply chain strategies, paving the way for sustained profitability and growth.

Keywords

Supply chain; System dynamics, Automotive industry, LARG paradigms.

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1. Introduction

The automotive industry requires robust supply chain strategies to cope with increasing complexity and market volatility. The Lean, Agile, Resilient, and Green (LARG) paradigms offer a comprehensive approach to enhancing supply chain performance by focusing on waste reduction, responsiveness, resilience, and sustainability (Akbarzadeh et al., 2019). The automotive industry is highly competitive and dynamic, requiring companies to continuously adapt and improve their supply chains to maintain a competitive edge (Divsalar et al., 2020). In this context, the role of supply chain management becomes critical (Rekabi et al., 2024). However, traditional, one-dimensional supply chain approaches are no longer sufficient to address the complexities and uncertainties of modern markets (Tavakol et al., 2023, Salahi et al., 2023). This research focuses on integrating the LARG paradigms into the automotive industry's supply chain,, particularly within the Iranian context. The LARG paradigm offers a comprehensive framework for enhancing supply chain performance (Jakhar et al., 2018). Lean principles aim to minimize waste and maximize value for customers; agile principles enhance the responsiveness to market changes (Saberifard et al., 2023); resilient principles improve the supply chain's ability to withstand disruptions (Kamali Chirani and Homayounfar, 2023), and green principles focus on environmental sustainability (Soufi et al., 2023). Integrating these paradigms can provide a holistic approach to managing supply chains in the automotive industry, ensuring efficiency, flexibility, robustness, and sustainability (Dubey et al., 2018).

Despite the theoretical advantages of the LARG paradigm, there is a lack of empirical studies evaluating its practical application and impact on the automotive industry's supply chain. This research addresses this gap by proposing a system dynamics model to evaluate the supply chain performance of SAIPA Automobile Company based on LARG principles.

Despite the theoretical benefits of the LARG paradigms, empirical evidence on their practical application and effectiveness in the automotive industry is limited (Homayunfar et al., 2018). This study aims to fill this gap by employing a system dynamics model to evaluate the supply chain of SAIPA Automobile Company. Through this approach, the study aims to provide actionable insights and strategies for improving supply chain performance, thereby contributing to the broader understanding of LARG paradigms in the automotive industry context. The automotive industry is a cornerstone of economic activity, characterized by intense competition and rapid change. Success in this industry hinges on maintaining a competitive supply chain (Lotfi et al., 2024). Traditional supply chain approaches often fail to address manufacturers' multifaceted challenges. This research aims to bridge this gap by applying the LARG paradigms to the supply chain of SAIPA Automobile Company. This study addresses how the LARG paradigms can be effectively integrated and evaluated within the automotive industry's supply chain. Specifically, this seeks to determine the most suitable scenarios for improving the supply chain performance of SAIPA Automobile Company through a system dynamics model.

Given the complexity and interdependencies within supply chains, a dynamic and holistic modeling approach is essential to capture the interactions and feedback loops among different elements. System dynamics modeling is particularly well-suited for this purpose as it simulates complex systems over time, providing insights into how various factors influence supply chain performance. The system dynamics model is employed in this study to evaluate the LARG supply chain elements because it enables the examination of dynamic behaviors and interrelationships within the supply chain. This approach allows us to simulate different scenarios and observe the long-term impacts of various strategies on supply chain performance. Using system dynamics, this study can develop and test dynamic hypotheses, visualize cause-and-effect relationships, and ultimately provide a robust framework for decision-making in supply chain management.

The remainder of the article is organized as follows. In the second section, a literature review of past research is presented. In the third section, the proposed framework of the problem is shown. The fourth section presents the results of applying the problem in the case study of SAIPA Automobile Company. Finally, in the fifth section, a general conclusion and suggestions for future research are presented.

2. Literature review

This section reviews the literature on the LARG supply chain paradigm and its application in various industries. For instance, Atefi et al. (2022) provided a dynamic model to measure the performance of a LARG supply chain with a balanced scorecard approach, using dynamic simulation to evaluate the performance. Atefi et al. (2021) also evaluated the LARG ness of a company's activities within a supply chain using a similar balanced scorecard and dynamic modeling approach. Sadeghi Moghadam et al. (2021) explored strategies to improve supply chain performance using LARG paradigms, highlighting strategies such as developing reverse logistics technology and creating electronic collaboration among supply chain members.

Izadyar et al. (2021) investigated the dynamic behavior of LARG supply chain management practices and their effect on sustainable performance in the automotive parts supply chain. They used fuzzy DEMATEL and fuzzy network analysis processes to prioritize practices and applied a system dynamics approach to evaluate sustainability performance. Shen et al. (2023) examined green product supply chains under uncertainty with government intervention, using theoretical game models to derive equilibrium decisions for different planning scenarios.

Karmaker et al. (2023) studied the challenges of implementing Industry 5.0 amidst multiple supply chain disruptions due to the COVID-19 pandemic. They used qualitative and quantitative methods to prioritize these challenges and analyze their interrelationships. Vergara et al. (2023) measured performance in resilient-sustainable supply chains using fuzzy multi-criteria techniques, focusing on the characteristics and influencing relationships within sustainable-resilient supply chains. Using structural equation modeling, Uddin (2022) explored the interactions between strategic alliances, supply chain cooperation, operational performance, and innovation performance.

Recent studies have also contributed significantly to the understanding of LARG supply chains. For example, a study titled "A System Dynamics Model of the LARG Supply Chain Diffusion in the Steel Industry of Yazd" developed a model to understand the diffusion process of LARG supply chain practices in the steel industry. Another study, "Developing the LARG-Effective Supply Chain Model Using a System Dynamics Approach," proposed a comprehensive model to evaluate the effectiveness of LARG supply chain practices. Additionally, Sonar et al. (2022) investigated the role of the LARGS (Lean, Agile, Resilient, Green, and Sustainable) paradigm in supplier selection, identifying important criteria and developing a hierarchical relationship among these criteria. Significant advancements have been made in LARG supply chain management in recent years. For instance, Atefi et al. (2022) and Atefi et al. (2021) utilized dynamic simulation and balanced scorecard approaches to evaluate LARG supply chain performance. Sadeghi Moghadam et al. (2021) proposed strategies for improving supply chain performance using LARG paradigms. Izadyar et al. (2020) investigated the sustainable performance of LARG supply chain management practices using fuzzy DEMATEL and network analysis processes, followed by a system dynamics evaluation.

Shen et al. (2023) examined green product supply chains under uncertainty, considering government intervention and using theoretical game models. Karmaker et al. (2023) analyzed the challenges of implementing Industry 5.0 amidst supply chain disruptions due to the COVID-19 pandemic, employing qualitative and quantitative methods. Vergara et al. (2023) focused on resilient-sustainable supply chains, utilizing fuzzy multi-criteria techniques to determine key characteristics and relationships. Using structural equation modeling, Uddin (2022) studied the impact of strategic alliances and supply chain cooperation on operational and innovation performance. To better illustrate the unique aspects of our study and how it differs from related works, Table 1 presents each study's key differences and contributions.

Table 1. Some related research

Study	Focus	Methodology	Key Findings	Contribution
Atefi et al. (2022)	LARG performance measurement	Dynamic simulation, balanced scorecard	Strategy map, indicators for LARG	Performance evaluation framework using dynamic simulation
Atefi et al. (2021)	LARG ness evaluation	Dynamic modeling, balanced scorecard	Integration of LARG and balanced scorecard	Evaluation of company's performance using LARG indicators
Sadeghi Moghadam et al. (2021)	LARG improvement strategies	Case study	Reverse logistics, closed-loop supply chain, electronic collaboration	Identification of effective strategies for LARG improvement
Izadyar et al. (2021)	Sustainable performance of LARG	Fuzzy DEMATEL, system dynamics	Prioritization of LARG practices	Sustainability performance evaluation of LARG practices
Shen et al. (2023)	Green supply chain under uncertainty	Theoretical game models	Government intervention effects	Decision-making framework for green supply chains
Karmaker et al. (2023)	Industry 5.0 and supply chain disruptions	Qualitative and quantitative methods	Challenges of Industry 5.0	Prioritization and analysis of implementation challenges
Our Study	LARG supply chain evaluation in automotive industry	System dynamics model	Long-term impact of LARG strategies on supply chain performance	Holistic evaluation framework for automotive supply chains

A review of the existing literature reveals a gap in empirical studies evaluating the practical application of LARG paradigms in the automotive industry's supply chain. While previous research has explored dynamic models and performance evaluation techniques, this study uniquely focuses on applying a system dynamics model to the LARG supply chain of SAIPA Automobile Company. By integrating LARG principles, we aim to provide a holistic evaluation framework that addresses efficiency, flexibility, resilience, and sustainability. This study advances the field by providing a comprehensive system dynamics model that evaluates the LARG supply chain elements in the automotive industry. This research offers new insights into the long-term impacts of various strategies on supply chain performance, thereby contributing to a deeper understanding of how LARG paradigms can be practically applied and measured in real-world scenarios. This study uniquely integrates LARG principles into a system dynamics model tailored to the automotive industry. Unlike previous studies focusing on individual elements or theoretical models, our research provides a comprehensive, empirical evaluation of LARG supply chain elements, offering actionable insights for improving supply chain performance in real-world scenarios. This study makes several incremental contributions to the existing body of knowledge in LARG supply chain evaluation. Firstly, this study provides a practical application of the LARG paradigms within the automotive industry, specifically focusing on the supply chain of SAIPA Automobile Company. Secondly, by employing a system dynamics model, we offer a robust framework for simulating and evaluating the long-term impacts of various LARG strategies on supply chain performance.

- This study provides empirical evidence on the effectiveness of integrating LARG principles in the automotive supply chain, highlighting the benefits of a holistic approach to supply chain management.
- This study introduces a novel system dynamics model that can simulate different scenarios and strategies, offering valuable insights for decision-makers in the automotive industry.
- This study's findings contribute to a deeper understanding of how LARG paradigms can be practically applied and measured, advancing the field of supply chain management by bridging the gap between theoretical concepts and real-world applications.

By addressing these aspects, our study not only fills existing gaps in the literature but also provides a comprehensive tool for practitioners to enhance supply chain performance by integrating LARG principles.

3. Methodology

System dynamics is an approach derived from computer basics used to analyze and solve complex problems, emphasizingpolicy analysis and design. Simulation using system dynamics models is very beneficial for learning the complexities of system dynamics. This attitude is a very valuable tool for identifying effective policies in existing systems and improving system behavior by using changes in its parameters and structural changes. This approach is an object-oriented simulation method based on feedback relationships, which, in addition to creating the participation of users of each model in its development, creates significant simplicity and speed in system definition and model development. One of the capabilities of this approach is the group development of models and the simplicity of model modification in response to system changes. The steps of the system dynamics method are:

- Problem statement
- Development of dynamic hypothesis
- Development of a simulation model
- Model testing
- Design and evaluation of policies

The system dynamics approach seeks to identify feedback closed loops to check the system's functioning. A feedback loop includes a closed chain of causal relationships affecting the primary variable in selection. Feedback loops include a positive feedback loop, also called a reinforcement loop. It also consists of negative feedback loops or, in other words, a balancing loop. These loops are loops in which if a component changes in one direction, it reinforces the loop of changes in the corresponding direction. Therefore, it can be acknowledged that the negative feedback loop is a loop in which if a component is changed in one direction, the desired loop will oppose the changes of that component in that direction. In short, it can be said that the negative loop has a neutralizing role and is against change. In the following, according to the identification of concepts and categories resulting from in-depth interviews with experts, according to the LARG supply chain paradigms, four causal loops were identified, according to which four dynamic hypotheses were presented.

(1) Lean Supply Chain Paradigm: Increasing the quality of products and services and improving quality control and supervision will lead to better customer support, enhanced coordination, reduced operating costs, increased profitability, competitive advantage, and overall supply chain efficiency.
(2) Agile Supply Chain Paradigm: Strengthening expertise and management skills, improving cooperation with suppliers, and enhancing risk management will increase organizational capability, innovation, and market responsiveness.
(3) Resilient Supply Chain Paradigm: Improving process flexibility and human resources management will improve production planning, inventory control, and logistics, enhancing supply chain resilience.
(4) Green Supply Chain Paradigm: Emphasizing legal requirements, social responsibility, and green practices will lead to optimized warehousing, production, and effective waste management, ultimately improving environmental sustainability and green marketing.

These hypotheses are directly linked to the research objectives of evaluating the impact of LARG paradigms on the supply chain performance of SAIPA Automobile Company. This article aims to identify effective strategies for enhancing supply chain efficiency, flexibility, resilience, and sustainability by testing these hypotheses through system dynamics modeling.

3.1. Validation of dynamics model

Validation of the model in this study is tested by matching the model's behavior with the real behavior. First, the historical data is drawn graphically, and the behavior of the model is compared. The question that needs to be answered in this regard is whether the model reproduces the model's behavior?. It means that the model's behavior can be matched with historical data. Can the simulated structure show the system's behavior in the real world? If the model can show the real world and match the historical data, it can be claimed that the model is validated. Validation in system dynamics models is divided into two types: structural validation and behavioral validation. Structural validation means creating relationships in the model that clearly and adequately represent the relationships of the real world (considering the study's purpose). Behavioral validation means that the model's behavior sufficiently represents the phenomenon's behavior in the real world. There will be no behavioral validation unless the model has adequate structural validation.

4. Findings

This section uses the system dynamics approach to address the hybrid modeling of the large supply chain in the automotive industry. The following identifies the components of the LARG supply chain paradigms for modeling. System dynamics is an approach derived from computer basics used to analyze and solve complex problems, emphasizing policy analysis and design. Simulation using system dynamics models is very beneficial for learning the complexities of system dynamics. This attitude is a very valuable tool for identifying effective policies in existing systems and improving system behavior by using changes in its parameters and structural changes. This approach is an object-oriented simulation method based on feedback relationships, which, in addition to creating the participation of users of each model in its development, creates significant simplicity and speed in system definition and model development. One of the capabilities of this approach is the group development of models and the simplicity of model modification in response to system changes.

The selection of variables and parameters was guided by their relevance to the automotive industry's supply chain and their impact on the LARG paradigms. The criteria included:

(1) **Relevance to Supply Chain Performance:** Variables were selected based on their direct impact on supply chain efficiency, flexibility, resilience, and sustainability. For example, product quality, process flexibility, and green production practices are critical for maintaining competitiveness in the automotive industry.
(2) **Data Availability:** Variables for obtaining reliable data were prioritized. Historical data from SAIPA Automobile Company and industry reports were used to validate the model.
(3) **Expert Input:** Industry experts provided insights into the most significant factors affecting the automotive supply chain. Their input was crucial in identifying resource utilization, network structure, and supplier cooperation variables.
(4) **System Dynamics Principles:** The selection of variables was also guided by system dynamics principles, focusing on feedback loops and causal relationships that drive system behavior.

The relevant paradigms and their variables are listed in Table 2.

Table 2. LARG supply chain paradigms for system dynamics modelling

Components of identified loops of lean paradigm	**Components of the identified loops of agile paradigm**
Quality of products and services	Strengthening the organization's capability
Quality control and monitoring	Risk management
Using a network structure	Uncertainty
Communication and interaction with stakeholders	Expertise and management skills
Coordination	Speed
Information and communications technology	Synergy
Financial planning and working capital management	Budgeting
Sharing information and knowledge	Responding to market needs
Attention to the flow of value and added value created	Development and focus on market
Customer support	Commitment
Operating costs	Innovation
profitability	Cooperation with suppliers
Supply chain efficiency	---------
Competitive advantage	---------
Utilization and optimal use of resources	---------
Components of identified loops of resilient paradigm	Components of identified loops of green paradigm
Process flexibility	Green production and operations
Human resources management	Choosing a green supplier
Contradiction, disruption, and conflict in the chain	Legal requirements, regulations, and standards
Logistics	Responsiveness to partners
Sourcing	Social responsibility
Integrity	Management of energy consumption and resources
Strategic alliance	Optimal warehouse management
Production planning and inventory control	Waste management
---------	Performance and monitoring factors
---------	Green marketing

As it is clear, investigating the model in the field of system dynamics consists of four steps, each of which is discussed below.

4.1. Definition of dynamic problem

As mentioned above, using a supply chain paradigm cannot create maximum efficiency for this chain, and each paradigm ignores some of the important indicators in the supply chain according to its strengths. Therefore, in establishing a LARG supply chain, in addition to making the most of the advantages of each of the four paradigms, it also covers the weaknesses of each of them, which is considered the most important factor in the dynamic problem.

4.2. Drawing causal diagrams and dynamic hypotheses

The system dynamics approach seeks to identify feedback closed loops to check the system's functioning. A feedback loop includes a closed chain of causal relationships affecting the primary variable in selection. Feedback loops include a positive feedback loop, also called a reinforcement loop. It also consists of negative feedback loops or, in other words, a balancing loop. These loops are loops in which if a component changes in one direction, it reinforces the loop of changes in the corresponding direction. Therefore, it can be acknowledged that the negative feedback loop is a loop in which if a component is changed in one direction, the desired loop will oppose the changes of that component in that direction. In short, it can be said that the negative loop has a neutralizing role and is against change. In the following, according to the identification of concepts and categories resulting from in-depth interviews with experts, according to the LARG supply chain paradigms, four causal loops were identified, according to which four dynamic hypotheses were presented.

4.2.1. The first dynamic hypotheses (presenting the circular causal model of the lean supply chain paradigm)

According to the identified factors, the attention of automobile companies to increase the quality of products and services and quality control and supervision makes them provide proper support to customers and thus take into account their needs and demands. On the other hand, by emphasizing information and communication technology, automobile companies can speed up communication and interaction with stakeholders, strengthening the process of sharing knowledge and information. The sum of these factors can increase coordination between them; meanwhile, using a network structure can also strengthen coordination. On the other hand, using a network structure helps automobile companies in financial planning, working capital management, and the use and optimal use of resources. With this support, financial planning and working capital management and the employment and optimal use of resources can significantly help to reduce operating costs, increase profitability, and improve the competitive advantage and efficiency of the supply chain; all these factors can help strengthen the value flow and strengthen the added value of the supply chain. Figure 1 illustrates the circular causal model of the lean supply chain paradigm.

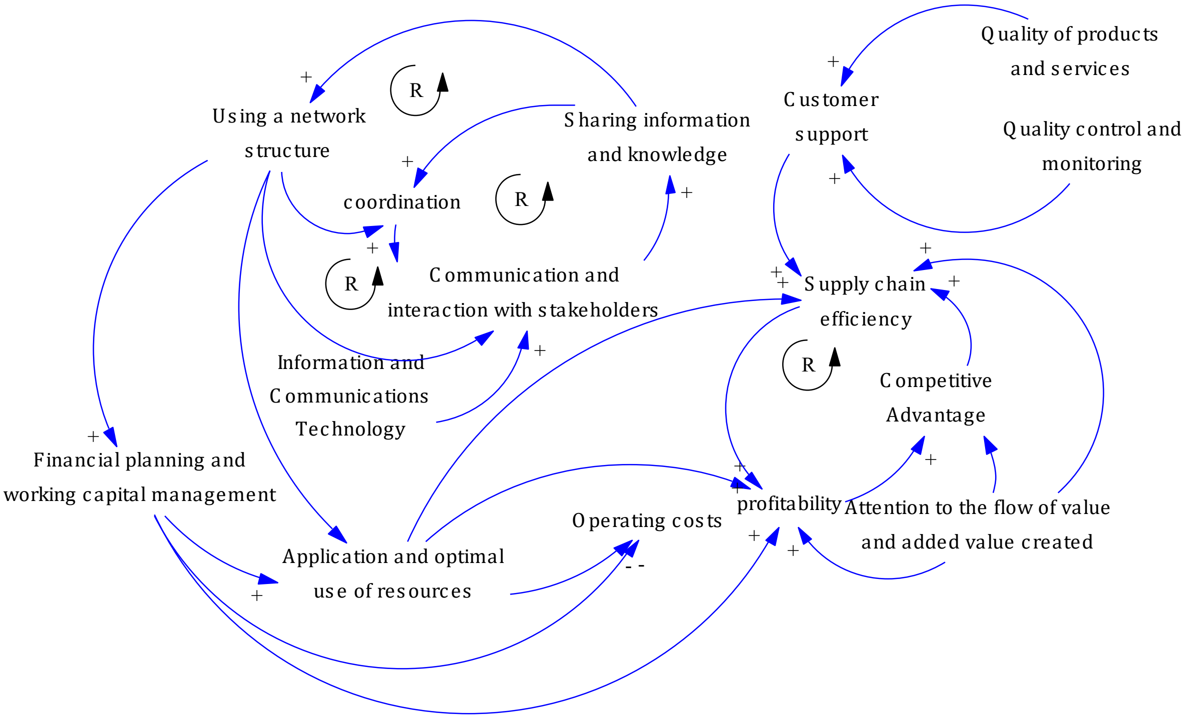

Figure 1. Presenting the circular causal model of the lean supply chain paradigm

4.2.2. The second dynamic hypotheses (presenting the circular causal model of the agile supply chain paradigm)

The expertise and management skills of automotive companies can provide special help to proper and long-term cooperation with suppliers, more appropriate risk management, strengthening the organization's capabilities, innovation, and appropriate budgeting. In this regard, strengthening the organization's appropriate budgeting can help strengthen its capabilities. Also, expertise and skills in management and synergy can help innovation in the organization, and in this way, the response to market needs can be strengthened. In the inter-model loop, speed affects synergy, and synergy affects commitment, and again, in the return loop, commitment affects speed, and this loop can continue incrementally. On the other hand, cooperation with suppliers can help to strengthen risk management, which reduces uncertainty. In the return loop, reducing uncertainty helps to strengthen risk management. In one of the loops, the development and focus on the market affects responding to market needs and strengthening the capacity of the organization's capabilities and strengthens them. Figure 2 displays the circular causal model of the agile supply chain.

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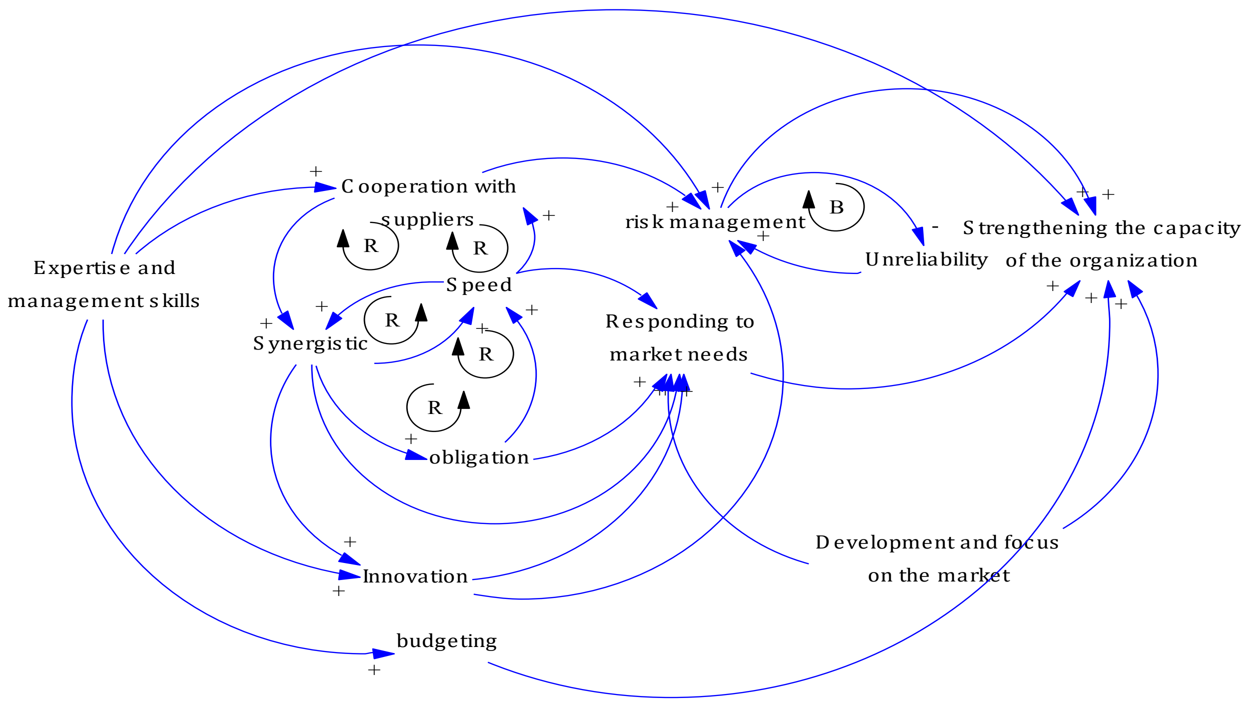

Figure 2. Presenting the circular causal model of the agile supply chain paradigm

4.2.3. The third dynamic hypotheses (presenting the circular causal model of the resilient supply chain paradigm)

The presence of skilled and expert human resources and their management in automotive companies can help the process flexibility of these companies. In this regard, the existence of expertise in human resources, along with process flexibility, can increase and improve the effectiveness of production planning and inventory control. On the other hand, process flexibility reduces conflict, disruption, and conflict in the supply chain and reduces them. In the other loop, production planning and inventory control strengthen process flexibility, and in the return loop, strengthening process flexibility leads to strengthening production planning and inventory control. Also, in one of the loops, process flexibility affects strengthening the logistics, and in the return loop, strengthening the logistics leads to strengthening of process flexibility. In one of the model loops, logistics leads to the strengthening of the strategic alliance, strategic alliance also strengthens integration, and in the next step, integration helps to strengthen sourcing, and finally, sourcing helps to strengthen logistics. In one of the loops of the model, integration leads to the development of sourcing, and the development and strengthening of sourcing leads to the development of integration. Figure 3 shows the circular causal model of the resilient supply chain paradigm.

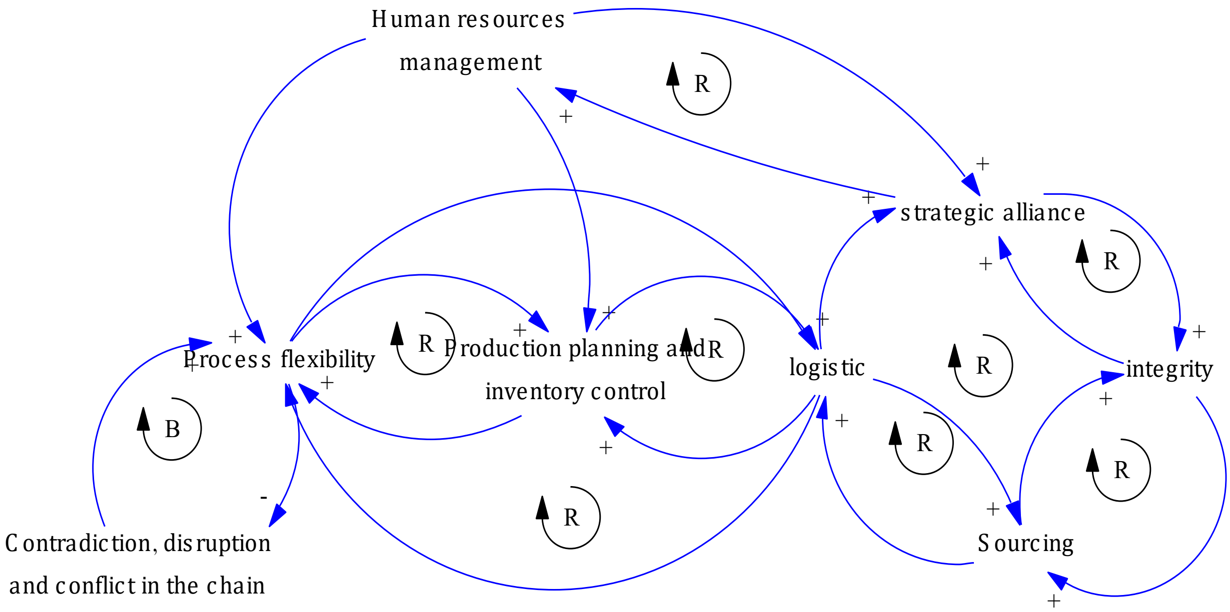

Figure 3. Presenting the circular causal model of the resilient supply chain paradigm

4.2.4. The fourth dynamic hypotheses (presenting the circular causal model of the green supply chain paradigm)

Emphasizing the legal requirements, regulations, and standards in automobile manufacturing can cause these companies to move towards more social responsibility, and increasing the attention of automobile manufacturing companies to social responsibility can help to choose green suppliers and require the company to choose suppliers that have the most indicators of greenness and also increase the company's responsiveness to its partners. Providing raw materials for automotive companies from suppliers can also optimize warehousing and prevent overstocking of raw materials, which can significantly help the establishment of green warehousing in automotive companies. Considering the conditions of green warehousing in the automotive industry and having raw materials with the least negative effects of pollution, the company's research and development process designs products. It provides samples in the form of pilot production for the production process. After investigating the performance indicators, the products are produced with maximum green indicators. In case of defects in production, corrective measures will be developed to fix them, and in this case, green production and operations in the company will be in the most optimal possible state. The attention of automotive companies in green production to reduce environmental pollution and pollutants and their efforts to reduce the effects of pollution lead to the management of energy consumption and resources in automobile manufacturing. Since the negative aspects of pollution in products are considered in green production, this factor can strengthen the company's ability to manage waste. Therefore, the production cycle is improved by identifying the weaknesses in the production line and reducing waste, as well as the policies of reducing production line waste and recycling waste. The product life is increased, which can encourage and motivate green consumers to use the company's products and services. In this way, the green marketing of automotive companies will be developed. It should be noted that the performance and regulatory factors of automotive companies should pay special attention to all these factors continuously. Figure 4 depicts the circular causal model of the green supply chain paradigm.

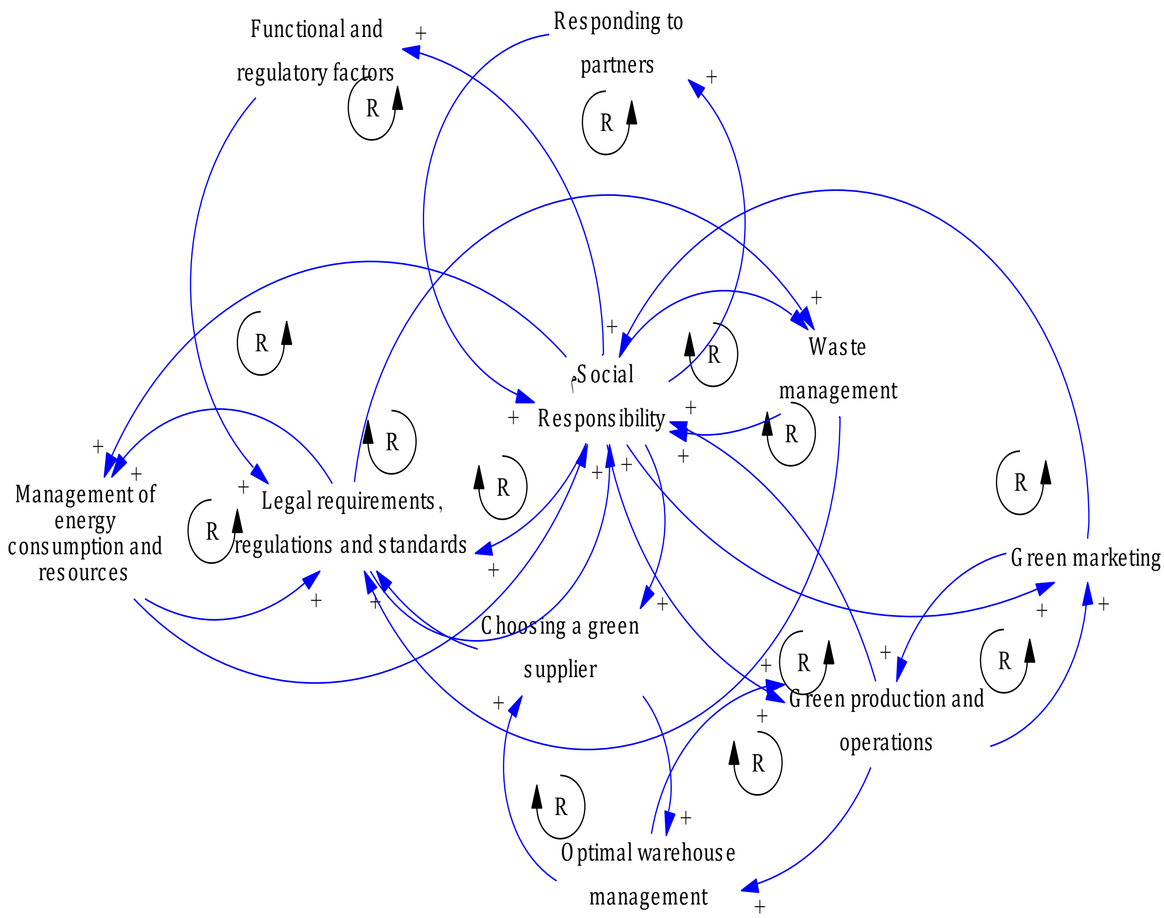

Figure 4. Presenting the circular causal model of the green supply chain paradigm

Finally, by identifying the circular causal model of the lean, agile, resilient, and green supply chain paradigm, the cause and effect and flow diagram based on the LARG supply chain are shown in Figure 5.

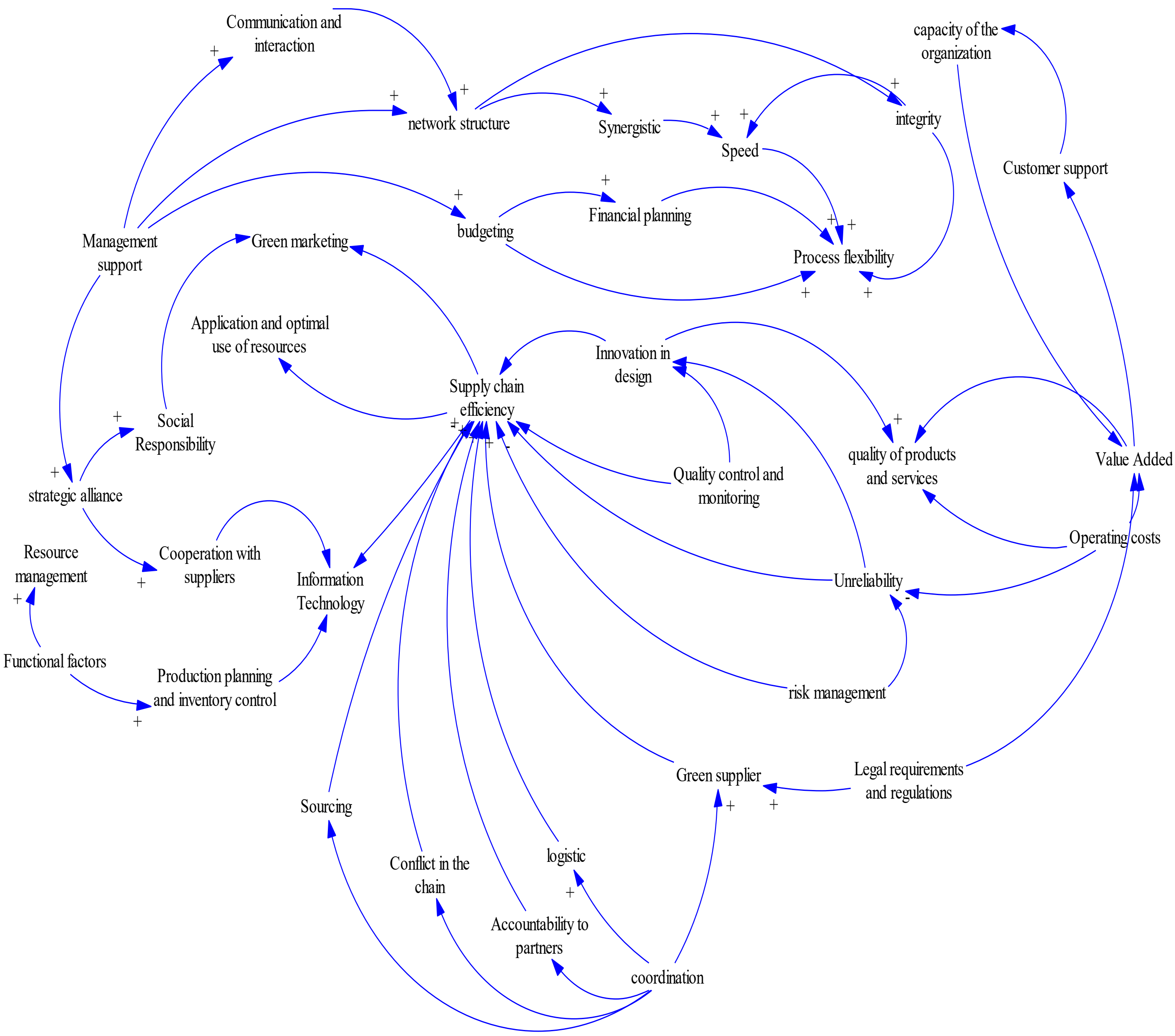

Figure 5. Cause and effect and LARG flow diagram

4.3. Drawing stock and flow diagrams

In this part of the research, the modeling of inventory-flow diagrams is shown in Figure 6. For the final modeling, Stock, flow, and auxiliary variables need to be identified, which are introduced in this section.

The system dynamics approach seeks to identify feedback closed loops to check the system's functioning. A feedback loop includes a closed chain of causal relationships affecting the primary variable in selection. Feedback loops include a positive feedback loop, also called a reinforcement loop. It also consists of negative feedback loops or, in other words, a balancing loop. These loops are loops in which if a component changes in one direction, it reinforces the loop of changes in the corresponding direction. Therefore, it can be acknowledged that the negative feedback loop is a loop in which if a component is changed in one direction, the desired loop will oppose the changes of that component in that direction. In short, it can be said that the negative loop has a neutralizing role and is against change. In the following, according to the identification of concepts and categories resulting from in-depth interviews with experts, according to the LARG supply chain paradigms, four causal loops were identified, according to which four dynamic hypotheses were presented:

1. Lean Supply Chain Paradigm
    - Positive Feedback Loop: Increasing product and service quality → Better customer support → Enhanced coordination → Reduced operating costs → Increased profitability → Competitive advantage → Improved supply chain efficiency.
    - Negative Feedback Loop: Improved quality control and monitoring → Reduction in operational defects → Lower operational costs → Increased profitability.
2. Agile Supply Chain Paradigm
    - Positive Feedback Loop: Strengthening management skills → Better supplier cooperation → Improved risk management → Enhanced organizational capability → Increased innovation → Better market responsiveness.
    - Negative Feedback Loop: Improved risk management → Reduced uncertainty → Enhanced stability in operations.
3. Resilient Supply Chain Paradigm
    - Positive Feedback Loop: Improved process flexibility → Better production planning and inventory control → Enhanced logistics → Strengthened strategic alliances → Improved sourcing → Enhanced resilience.
    - Negative Feedback Loop: Better management of disruptions → Reduced conflicts and inefficiencies → Enhanced process stability.
4. Green Supply Chain Paradigm
    - Positive Feedback Loop: Emphasis on legal requirements and social responsibility → Choosing green suppliers → Optimized warehousing → Improved green production and operations → Effective waste management → Better green marketing.
    - Negative Feedback Loop: Improved waste management → Reduction in environmental impact → Enhanced sustainability.

It should be noted that from the modeling of the four paradigms, the mathematical equations introduced in Table 3 were extracted for the final analysis.

Table 3. Introduction of the problem variables and their operational definition

No.	Variable	Type	Mathematical relation
1	Attention to quality of products and services	Auxiliary	0.1(f5(Green Design)
2	Attention to quality control and monitoring	Auxiliary	IF THEN ELSE (human resource=>0.1,0.4, IF THEN ELSE (human resource-es =>0.09,0,0.2))
3	Using a network structure	Auxiliary	RAMP (Green Product Quality,1,9) -((0.2*Government support) +Orders for green products-green production)
4	Communication and interaction with stakeholders	Auxiliary	Skilled human resources/30
5	Coordination	Auxiliary	SMOOTH (human resources*0.2,1)
6	Information and communications technology	Auxiliary	F3(training)
7	Financial planning and working capital management	Auxiliary	(STEP (Green recovery,2) +Managers Support+(2*Media support))
8	Sharing information and knowledge	Auxiliary	(SMOOTH (Change in the rate of orders, 10))
9	Attention to flow of value and added value created	Auxiliary	F1(Media support)
10	Customer support	Auxiliary	SMOOTH (0.3,1)
11	Operating costs	Auxiliary	SMOOTH (human resources,2)
12	Profitability	Flow	STEP (0.5, Government support) +(1/Green Product Price)
13	Supply chain efficiency	Auxiliary	0.59
14	Competitive advantage	Stock	(STEP (Green recovery,2) +Managers Support+(2*Media support))
15	Utilization and optimal use of resources	Auxiliary	(SMOOTH (Change in the rate of orders, 10))
16	Strengthening the capacity of the organization	Auxiliary	F1(Media support)
17	Risk management	Auxiliary	Skilled human resources/30
18	Uncertainty	Auxiliary	SMOOTH (human resources*0.2,1)
19	Expertise and management skills	Flow	0.4/Skilled human resource
20	Speed	Auxiliary	(STEP (Green recovery,2) +Managers Support+(2*Media support))
21	synergy	Auxiliary	(SMOOTH (Change in the rate of orders, 10))
22	Budgeting	Auxiliary	F1(Media support)
23	Responding to market needs	Flow	(STEP (Green recovery,2) +Managers Support+(2*Media support))
24	Development and focus on market	State	(SMOOTH (Change in the rate of orders, 10))
25	Management commitment and support	Auxiliary	F1(Media support)
26	Innovation in design	Auxiliary	F4(Supervision over implementation of Laws and regulations)
27	Cooperation with suppliers	Auxiliary	(STEP (Green recovery,2) +Managers Support+(2*Media support))
28	Process flexibility	Auxiliary	(SMOOTH (Change in the rate of orders, 10))
29	Human resources management	Flow	SMOOTH (human resources,2)
30	Contradiction, disruption, and conflict in the chain	Auxiliary	SMOOTH (human resources,2)
31	Logistics	Auxiliary	IF THEN ELSE (Green fuel>=0.9, SMOOTH (0.8,2), f2(Green fuel))
32	Sourcing	Auxiliary	RAMP (Green Product Quality,1,9) -((0.2*Government support) +Orders for green products-green production)
33	Integrity	Auxiliary	SMOOTH (human resources,2)
34	Strategic alliance	Auxiliary	RAMP (0.09, 0, 10)
35	Production planning and inventory control	Auxiliary	(0.3+(f4(Supervision over implementation of Laws and regulations))

No.	Variable	Type	Mathematical relation
36	Green production and operations	Flow	((0.2*Green Design) +(0.1*Green Suppliers) +(0.2*Technology) +(0.2*Order for green products) +(0.15*Skilled Human Resources) +(0.3Supervision over implementation of Laws and regulations))
37	Choosing a green supplier	Auxiliary	(0.2+(0.7* Supervision over implementation of Laws and regulations))
38	Legal requirements, regulations, and standards	Auxiliary	(0.3+PULSE TRAIN (1, Government support,9,9)
39	Responsiveness to partners	Auxiliary	0.3+RAMP (Managers support, 1,9)
40	Social responsibility	Auxiliary	Employment-HR Quit Rate-Skill enhancement
41	Management of energy consumption and resources	Auxiliary	0.3+f4(Supervision over implementation of Laws and regulations)
42	Optimal warehouse management	Stock	(Green production)-(sales)
43	Waste management	Flow	0.1+(0.3*Government support) +(0.5* Supervision over implementation of Laws and regulations)
44	Performance and monitoring factors	Auxiliary	(0.2) +SMOOTH (Rule, 2)
45	Green marketing	Auxiliary	Employment-HR Quit Rate-Skill enhancement
46	Recruiting expert staff by other companies	Flow	IF THEN ELSE (human resource>=0.1,0.4, IF THEN ELSE (human resource-es>=0.09,0,0.2))
47	Extreme price fluctuation	Flow	RAMP (Green Product Quality,1,9) -((0.2*Government support) +Orders for green products-green production)
48	Retirement rate of professionals	Flow	Skilled human resources/30
49	Dismissal rate	Flow	SMOOTH (human resources*0.2,1)
50	Skilled workforce	State	(Skill Enhancement-Job quit rate-retirement rate)
51	Human resources	State	Employment-HR Quit Rate-Skill enhancement
52	Income	State	Sales

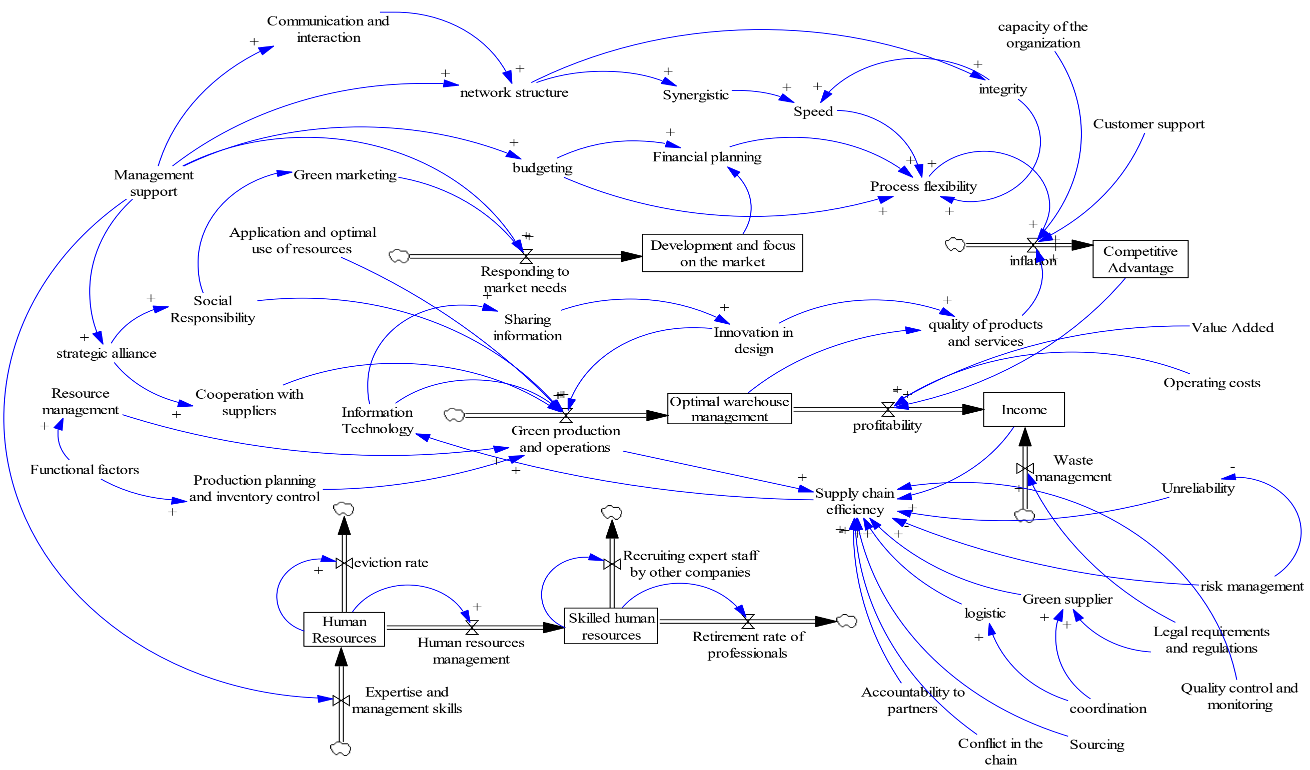

Figure 6. LARG supply chain model for automobile companies

According to the definition of state variables in the simulation model and the initial value surveyed by the experts, the level of competitiveness according to the effective factors is increasing over time, indicating the logical behavior of the model. Figure 7 shows changes in competitiveness in the simulation of competitive advantage in 100 months. Moreover, Figure 8 displays that according to the initial number of surveys by the experts, the level of development and focus on the market is increasing over time, showing the logical behavior of the model.

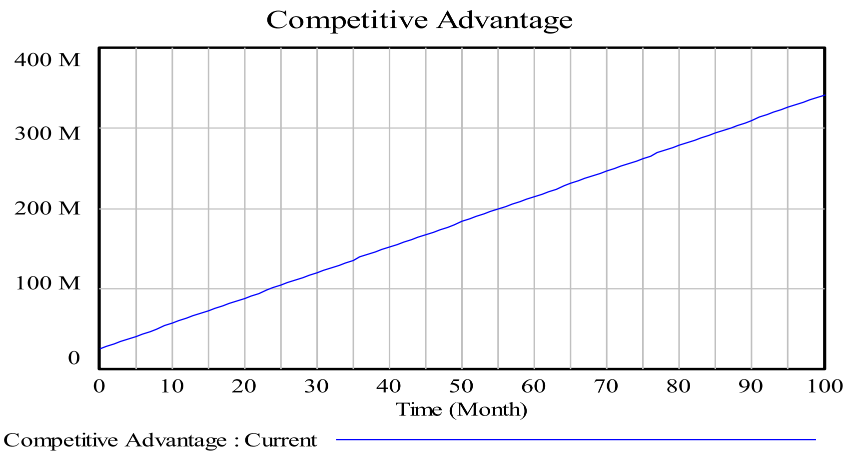

Figure 7. Simulation of competitive advantage over time

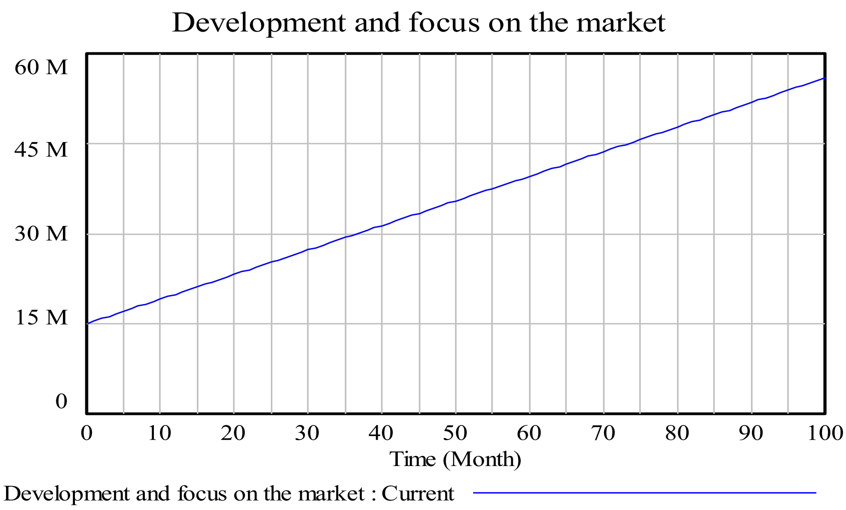

Figure 8. Simulation of development and focus on market over time

Model validation is one of the most important stages of modeling. Since the system dynamics model usually represents the real operation of real systems in some aspects, it is necessary and important for the model to be close to the real world to verify the model. In order to validate, the behavior of the model was examined, and some model variables were subjected to abrupt changes and boundary conditions. As seen in Figure 9, the income decreased significantly with the decrease in customer orders delivered. On the other hand, with the increase in the delivery of customer orders, the income increased.

Figure 9. Boundary test related to the number of customer order deliveries according to income

In addition to the boundary test, a test to reproduce the participants' behavior was considered. In this case, the simulated behavior for the model is reproduced to be compared with the real data. Figure 10 illustrates that according to the initial value surveyed by experts, experts' retirement rate is increasing over time, showing the logical behavior of the model.

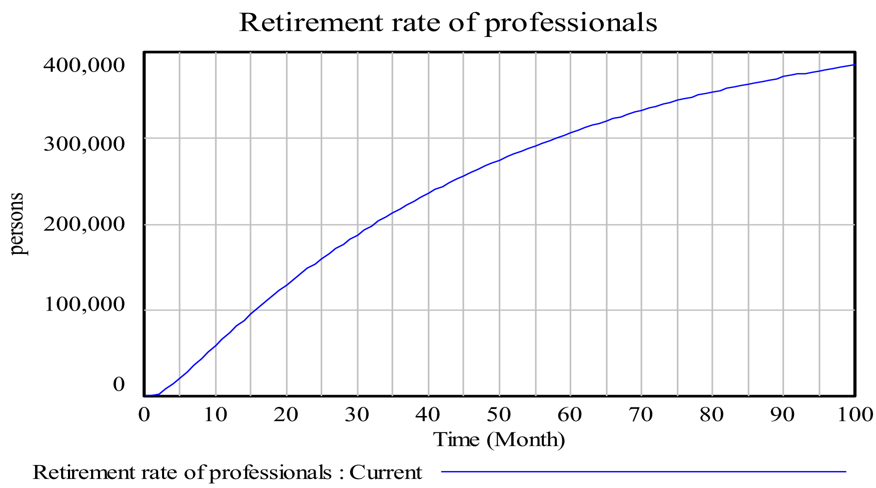

Figure 10. Graph of the retirement rate of experts over time

Figure 11 depicts that according to the initial value surveyed by the experts, the level of human resource management according to the effective factors increased up to one-fifth of the simulation period and then remained constant until the end of the predicted period, indicating the logical behavior of the model.

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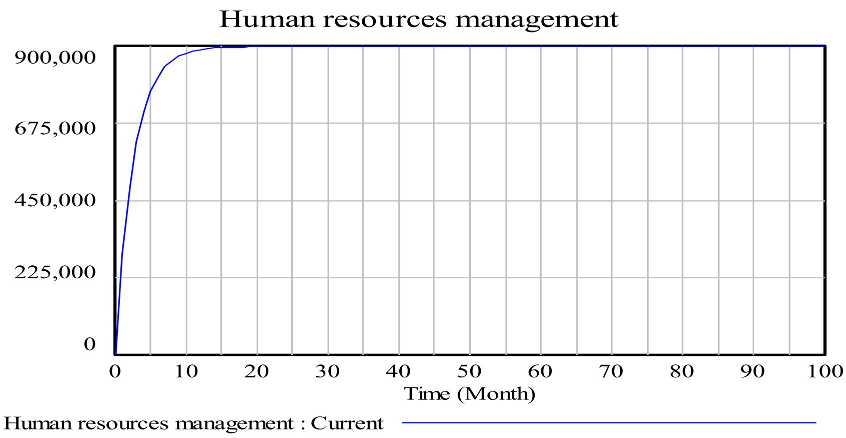

Figure 11. Graph of human resource management over time

Validation of the model in this study is tested by matching the model's behavior with real behavior. First, historical data is drawn graphically, and the model's behavior is compared. The question that needs to be answered in this regard is whether the model reproduces the behavior of the real system. The model's behavior can be matched with the historical data. If the model can show the real world and match the historical data, it can be claimed that the model is validated. Validation in system dynamics models is divided into two types: structural validation and behavioral validation.

- **Boundary Adequacy Test:** Ensures that the model includes all relevant variables and excludes irrelevant ones. The boundary adequacy test confirms that the selected variables and parameters sufficiently capture the system dynamics of the automotive supply chain.
- **Boundary Condition Test:** The boundary condition test ensures the model performs correctly under extreme conditions. This test involves setting model variables to extreme values and observing the system's response. For example, reducing the number of customer order deliveries to zero should significantly decrease income, which is validated by the model's behavior (Figure 9).
- **Integrity Error Test:** Ensures no logical or computational errors in the model. This test involves checking the consistency and accuracy of the model equations and their implementation.
- **Behavior Reproduction Test:** Compares the model's simulated behavior with real-world historical data. For instance, the model accurately simulates the retirement rate of experts over time (Figure 10), showing logical behavior.
- **Error Measurement Test:** Quantifies the deviation between the model's simulated output and actual historical data. The model's predictions should closely match real-world data, indicating high accuracy.

5. Scenario Planning

In order to achieve the most important goal of modeling dynamic systems, it is necessary to investigate different potential policies for strengthening and improving the model's performance. Among the scenarios or the proposed policies, the policy providing the best result is selected for implementation in the desired system. For this reason, after measuring the model's validity and when the research experts reach a consensus, the results obtained from investigating the scenarios can be used to evaluate different policies to improve the system. For this purpose, in the present research, after validating the model, it was used to run a simulation experiment, and the results obtained are presented below. This research, considered eight scenarios, and the economic consequence or income was considered as the basis of scenario creation.

Examining several possible policies for enhancing and strengthening the model's performance is essential to achieving the main objective of modeling dynamic systems. The scenarios were created based on expert input and the key variables identified in the system dynamics model. Each scenario focuses on a specific aspect of the LARG paradigms, aiming to evaluate the impact of different strategies on the supply chain's performance.

(1) **Expert Consultation:** Experts from the automotive industry were consulted to identify the critical variables and parameters affecting the supply chain's performance.
(2) **Identification of Key Variables:** Variables such as resource utilization, network structure, product quality, process flexibility, supply chain efficiency, strategic alliances, and performance monitoring were identified as critical factors.
(3) **Scenario Definition:** Eight scenarios were defined to simulate the impact of changes in these key variables on the supply chain's performance. Each scenario focuses on strengthening a specific aspect, such as resource utilization, network structure, or process flexibility.
(4) **Simulation and Analysis:** The scenarios were simulated using the system dynamics model, and the results were analyzed to determine the impact on income and other performance metrics.

5.1. The level of income or economic consequences scenario by strengthening the utilization and optimal use of resources

In this scenario, the income is changed to an equal state. The simulation of the model about the level of income or economic consequences by strengthening the utilization and optimal use of resources shows that the optimal level of income by strengthening the utilization and optimal use of resources in the maximum state is more suitable than the equal state. In the equal state, it is more suitable than the current state. As can be seen in this scenario, the trend of changes from 1390 to 1398 (2011 to 2019) was not very noticeable, but from 1398 to the end of the simulation period, it faced an increasing trend and exponential growth, as shown in Figure 12.

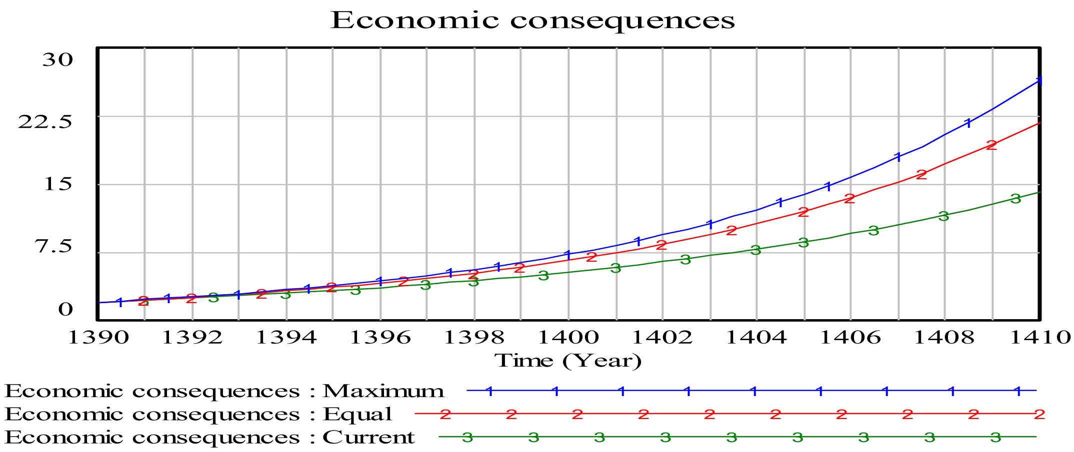

Figure 12. Simulation of the first scenario

5.2. The level of income or economic consequences scenario by strengthening the use of the network structure

In this scenario, the model simulation about the income level by strengthening the use of the network structure shows that the income level by strengthening the use of the network structure in the maximum state is better than the equal state. In the equal state, it is better than the current state. Of course, it is acknowledged that the distance between the equal state and the maximum state from the beginning of the simulation time to 1406 (2027) is very close, and from 1406 to the end of the period, there is almost a noticeable and significant increase as shown in Figure 13.

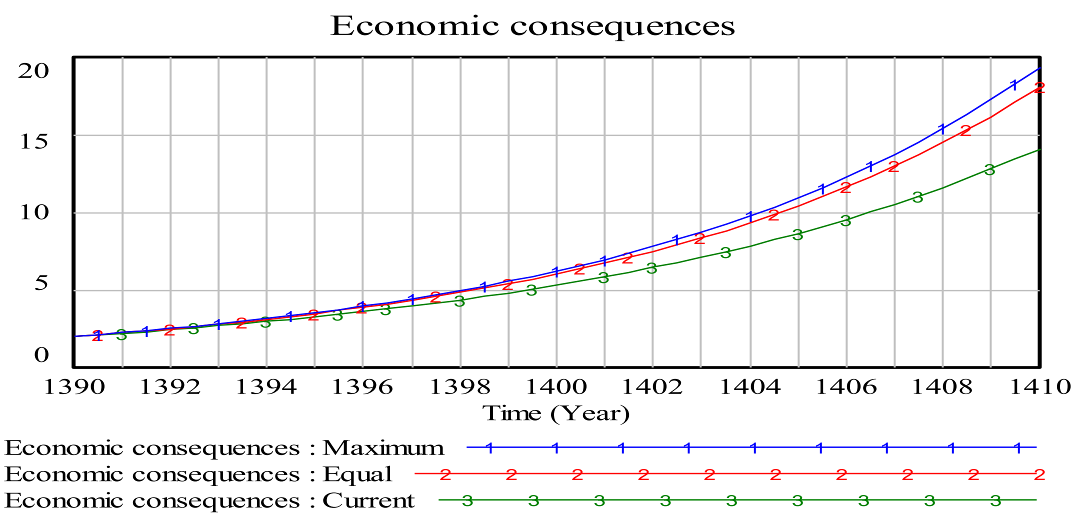

Figure 13. Simulation of the second scenario

5.3. The level of income scenario according to the quality of products and services

In this scenario, the simulation of the model about the level of economic consequences or income according to the quality of products and services shows that the level of income according to the quality of products and services in the maximum state is higher than in the equal state and in the equal state it is higher than the current state. Of course, it is acknowledged that the distance between the equal state and the maximum state from the beginning of the simulation period to the year 1406 is very close, and from the year 1406 to the end of the period, the increasing trend is almost noticeable, as shown in Figure 14.

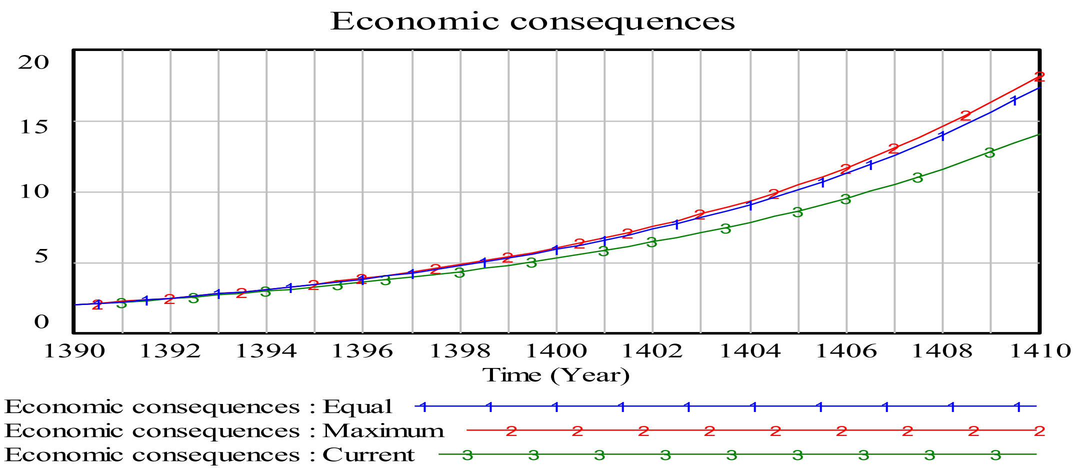

Figure 14. Simulation of the third scenario

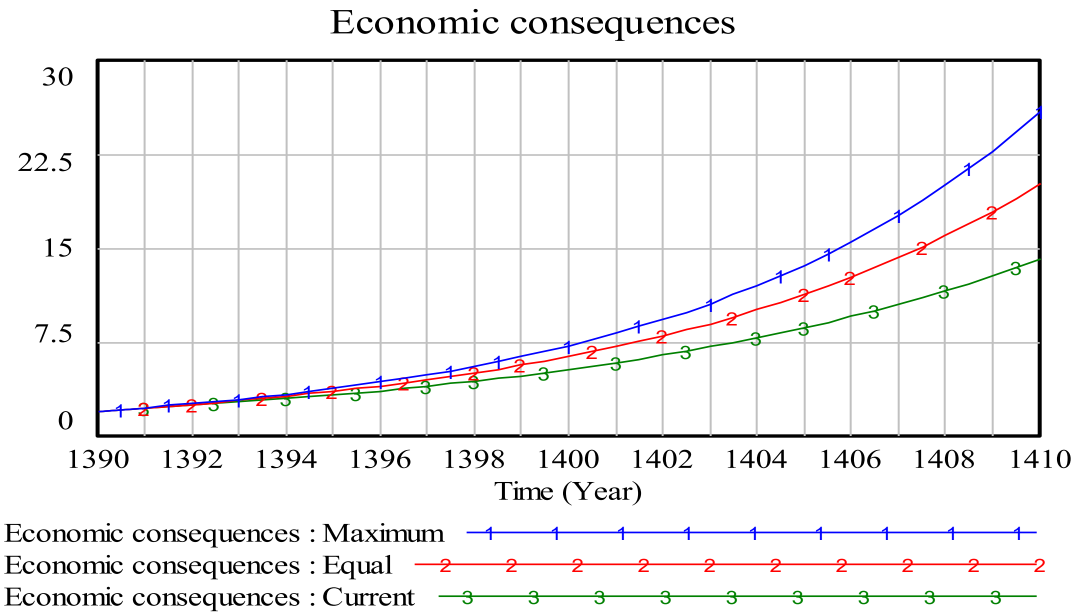

Figure 15. Simulation of the fourth scenario

5.4. The level of income scenario according to process flexibility

In this scenario, the simulation of the model about the level of income according to process flexibility shows that the level of income according to process flexibility in the maximum state is higher than in the equal state, and it is higher in the equal state than the current state. It should be noted that these changes from 1390 to 1400 (2011 to 2021) in the simulation period were not significant. However, from 1400 to the end of the simulation period, there is an increasing and noticeable trend, as shown in Figure 16.

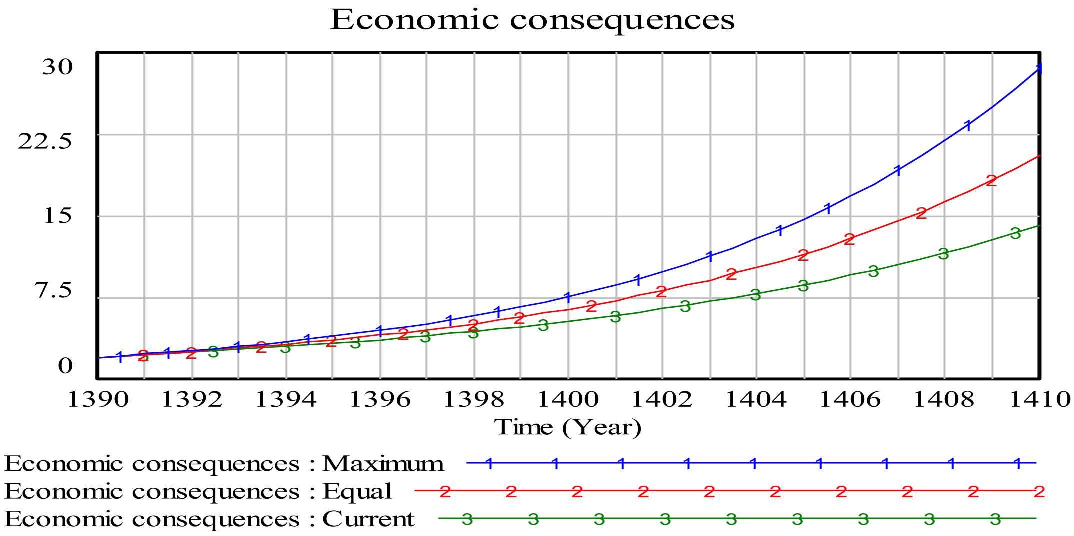

Figure 16. Simulation of the fifth scenario

5.5. The level of income scenario according to the efficiency of the supply chain

In this scenario, the simulation of the model regarding the level of income according to the efficiency of the supply chain shows that the level of income according to the efficiency of the supply chain in the maximum state is higher than the equal state and in the equal state it is higher than the current state. It should be noted that the difference between the simulations was not very noticeable in these changes from 1390 to 1396 (2011 to 2017). However, from 1396 to the end of the simulation period, the state of the maximum level of income related to the efficiency of the supply chain showed an increasing and noticeable trend, as shown in Figure 17.

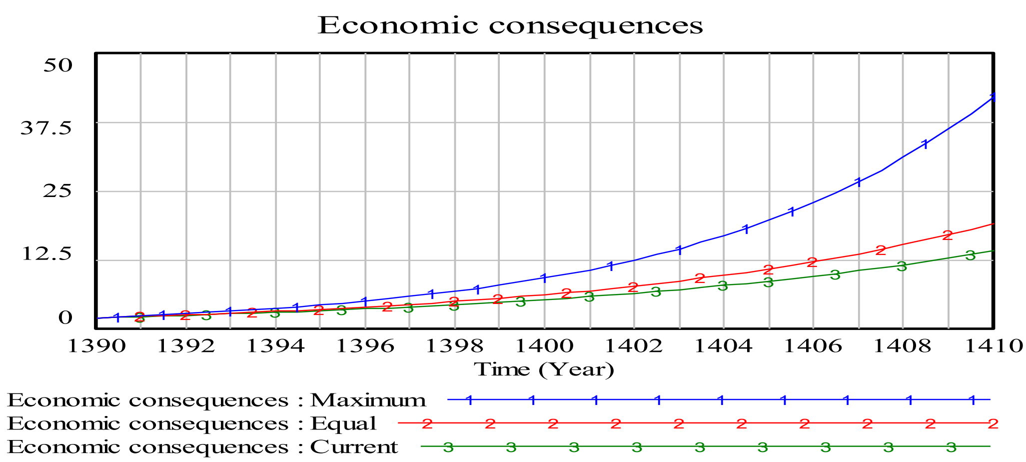

Figure 17. Simulation of the sixth scenario

5.6. The level of income scenario according to strategic alliance

In this scenario, the simulation of the model about the income level according to the strategic alliance shows that the income according to the strategic alliance is higher than the equal state in the maximum state and higher than the current state in the equal state. It should be noted that these changes from 1390 to 1400, the difference between the simulations was not very significant, but from 1401 (2022) to the end of the simulation period, the state of maximum income due to the strategic alliance has a noticeable increasing trend, as shown in Figure 18.

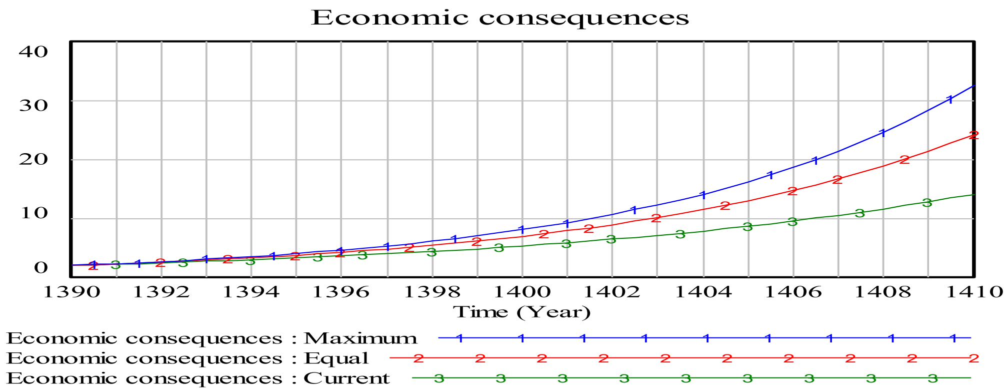

Figure 18. Simulation of the seventh scenario

5.7. The level of income scenario according to performance and monitoring factors

In this scenario, the simulation of the model regarding the income level according to the performance and monitoring factors shows that the income level according to performance and monitoring factors is higher in the maximum state than the equal state, and it is higher in the equal state than the current state. It should be noted that the difference between the simulations from 1390 to 1404 (2011 to 2025) was not very noticeable. However, from 1404 to the end of the simulation period, the state of the maximum income level has an increasing trend according to performance and monitoring factors (Figure 19).

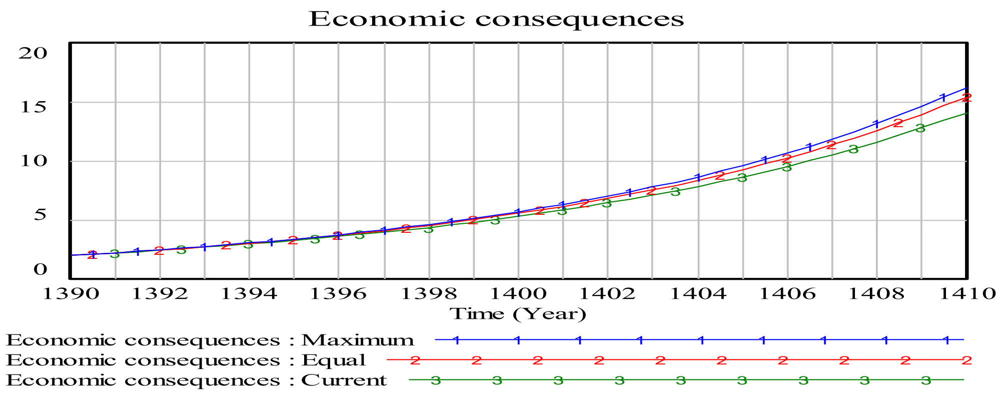

Figure 19. Simulation of the eighth scenario

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6. Conclusion

In this research, a system dynamics model was proposed to implement paradigms related to LARG policy in the suppliers of SAIPA Company. For this purpose, first, the components of the research dynamic model were identified. Specific models of each paradigm were presented in each section related to the four paradigms. Finally, the research dynamic model was presented by combining four approaches (lean, agile, resilient, and green). It should be noted that to reach the final model of the research, four dynamic hypotheses were developed according to the four paradigms. In general, with these interpretations, 52 variables were identified in the dynamic model of the research, which included auxiliary, state, and flow variables. This model included 52 variables, comprising auxiliary, state, and flow variables, which were used to simulate eight different scenarios, as shown in Table 4.

Table 4. Summary of scenario analysis result

Scenario Number	Scenario Description	Reason for Results
1	Utilization and Optimal Use of Resources	Improved resource utilization leads to higher operational efficiency and cost savings, directly enhancingincome.
2	Use of Network Structure	Strengthening network structures enhances collaboration and information sharing, which improves overall supply chain coordination and performance.
3	Quality of Products and Services	High product and service quality increases customer satisfaction and loyalty, increasing sales and income.
4	Value Flow and Added Value Created	Efficient value flow and the creation of added value streamline processes and reduce waste, resulting in increased profitability.
5	Process Flexibility	Process flexibility allows for quicker adaptation to market changes and customer demands, leading to improved income levels.
6	Supply Chain Efficiency	Enhanced supply chain efficiency reduces costs and improves delivery times, significantly boosting income.
7	Strategic Alliance	Strategic alliances foster strong partnerships and collaboration, improving supply chain resilience and performance.
8	Performance and Monitoring Factors	Effective performance monitoring ensures continuous improvement and alignment with strategic goals, positively impacting income.

The highest income increase was observed in Scenario 6, emphasizing supply chain efficiency, followed by Scenario 5, focusing on process flexibility. Scenario 4 highlighted the importance of efficient value flow and added value in improving profitability. Scenarios 2 and 3 demonstrated the benefits of strong network structures and high product quality. According to the results obtained and the trend analysis of the graphs related to the research scenarios, the greatest change was related to the sixth scenario, which refers to the role of the supply chain's efficiency in increasing the income level. The next scenario is Scenario 5, referring to increasing the level of income due to process flexibility. In third place is Scenario 4, which refers to increasing the income level according to the value flow and added value created. For future research, it is suggested that a hybrid approach using a mathematical programming model and system dynamics be provided to analyze LARG paradigms. The research's key findings are:

- Enhancing supply chain efficiency significantly boosts income, underscoring the importance of optimizing processes and reducing costs.
- Flexibility allows quick adaptation to market changes, highlighting the need for dynamic and responsive supply chain strategies.
- Efficient value flow and added value creation improve profitability, emphasizing the need for continuous process improvement and waste reduction.
- Strong partnerships enhance resilience and performance, suggesting that companies should invest in building and maintaining strategic alliances.
- According to the results, practical suggestions are as follows:
- Companies should optimize their supply chain processes to reduce costs and improve delivery times.
- Implementing flexible processes can help companies quickly adapt to market changes and customer demands.
- Building strong partnerships can enhance supply chain resilience and overall performance.

The model relies on historical data and expert input, which may not fully capture future uncertainties and market dynamics. The study focuses on the automotive industry, and findings may not be directly applicable to other industries without modifications. Future research could explore the integration of LARG paradigms with other supply chain management strategies, such as digitalization and Industry 4.0 technologies. Investigating the application of LARG paradigms in other industries, such as healthcare or electronics, can provide insights into their broader applicability and benefits. Developing hybrid models that combine mathematical programming with system dynamics can offer a more comprehensive analysis of LARG paradigms. Examining the impact of external factors, such as geopolitical changes and environmental regulations, on the implementation and effectiveness of LARG paradigms can provide valuable insights for practitioners.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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