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A System Dynamics Model of the LARG Supply Chain Diffusion in the Steel Industry of Yazd

Mohammad Hassan Alavi Sadr[1], Ali Morovati Sharifabadi[2], Davood Andalib Ardakani[2]

[1]Ph.D Student, Department of Industrial Management, Faculty of Economic, Management and Accounting, Yazd University, Yazd, Iran

[2]Associate Professor, Department of Industrial Management, Faculty of Economic, Management and Accounting, Yazd University, Yazd, Iran

ABSTRACT:

The supply chain is currently threatened by technological advancements, market fluctuations, environmental concerns, government regulations, and unanticipated events. In this context, the LARG paradigm makes the supply chain resistant to disruptions, reduces adverse environmental effects, responds to market, customer, and technological changes, and minimizes waste. Efficient supply chain management in the steel industry is crucial due to its fundamental role in the national economy and societal well-being. LARG supply chain simulations in the steel industry using system dynamics can identify input-output relationships, specify internal feedback levels, and model system behavior at different time intervals based on available information. Despite the significance of this issue, previous research has paid limited attention to this topic. This study aims to present a system dynamics model of the LARG supply chain in the steel industry of Yazd in light of the prevailing production strategies in the steel industry and the impact of regional GDP changes on steel production. The results indicate that the proposed model has the capacity to predict and interpret real-world conditions and reasonably describe the trends of supply chain changes. Additionally, it provides an effective tool for steel industry managers to enhance and optimize the supply chain in the face of challenges and environmental changes. The variables in the model in optimistic and pessimistic scenarios show that changes in the ratio of iron waste production, iron ore production ratio, production waste percentage, and iron ore reserves have a direct and noticeable impact on the resilience, flexibility, agility, and sustainability of the supply chain.

KEYWORDS: Supply Chain, System Dynamics, Simulation, Steel Production Strategies

Introduction

As a broad and practical concept, the supply chain interconnects various efforts and activities within an organization, ranging from raw material procurement to the distribution of final products (Ezdemir et al., 2022) and globalization. Today, supply chains face significant challenges, including rapid market changes, dynamic and unpredictable customer demands, advancements in communication and information systems, increased government regulations, environmental concerns, and unexpected events (Tayebi et al., 2023).

The notion of the "large-scale" paradigm has surfaced amidst a range of supply chain paradigms, which encompass lean paradigms for cost reduction and waste elimination, agile paradigms for quick responsiveness to market changes and customer needs, green paradigms for reducing environmental impacts, and resilience paradigms for coping with unexpected disruptions (Rout, 2021). The LARG paradigm in the supply chain seeks to bring together the four previous paradigms within the supply chain space to harness the advantages of each while mitigating their shortcomings (DeSouza et al., 2019). In other words, it strives to make the supply chain resilient against disruptions, reduce adverse environmental impacts, be responsive to market changes, customers, and technology, and minimize waste as much as possible (Butani, 2022).

Given its vital role in meeting industrial and construction needs, the steel industry is considered one of the fundamental and strategic sectors in the economy of any country. Steel is regarded as one of the most strategic industrial commodities globally, and its production and consumption levels are indicators of progress within a society (Pinto & Dimar, 2020). This foundational industry plays a fundamental role in the national economy and the welfare of society. Therefore, paying attention to its supply chain and efficient management is essential and undeniable (Meng et al., 2021).

The steel production supply chain begins with the supply or production of raw materials such as iron ore and other additives. Subsequently, it involves the production of final steel products such as billets, sheets, and so on. Intermediate products such as concentrates, slabs, or sponge iron are also produced and delivered to end consumers and downstream industries. Therefore, it encompasses a wide spectrum of suppliers, producers, and customers, resulting in increased complexity, sensitivity, and risk across various stages of raw material procurement, production, storage, logistics, marketing, and sales in this industry. For this reason, the management and simulation of these processes can provide the conditions for assessing and examining hidden influential factors with the aim of improving the performance of the steel industry's supply chain.

An examination of scholarly literature from 2010 to the mid-2020s reveals that researchers prioritize implementing economic factors, including cost reduction and linear and nonlinear mathematical models, in an effort to improve the performance of the steel industry's supply chain (Walton, 2020). Many of these models have considered various supply chain approaches, such as green supply chains and resilience. However, fewer studies have simultaneously emphasized these approaches within the framework of a large-scale supply chain. This is due to the complexity of managing and coordinating various supply chain segments, each with its own dynamics, amidst a vast quantity of information and influential factors, and determining their interrelationships and the magnitude of their effect on the system's overall performance through mathematical models. Approaches such as system dynamics can address these challenges effectively. As such, not only can the input-output relationships be determined, but also the extent of feedback from internal factors can be identified, and the system's behavior can be modeled over different time periods based on the available model information.
Surveys have indicated that there is a dearth of research on the use of a system dynamics approach in modeling the steel supply chain and key strategies in steel production. Additionally, factors such as time, delays in iron ore production development, attention to the rate of iron waste production, and changes in regional GDP have not been sufficiently examined in this context. Another significant issue is the lack of attention to the simultaneous deployment of supply chain paradigms in the steel supply chain, especially within the context of a large-scale supply chain. Therefore, this research aims to present a dynamic model of the steel supply chain in Yazd province, Iran. This model considers the LARG paradigm and incorporates such parameters as the use of recycled steel in the production cycle, the quality of steel waste, and the reduction of losses in the steel recycling process. Furthermore, it considers regional GDP, the development of iron ore production, and the rate of iron waste production within the framework of steel production strategies.

Research Background

Various researchers have examined different supply chain paradigms in various industries using dynamic system modeling. Sharma et al. (2022) have delved into this subject. In their research, they focused on examining the sustainability of the supply chain during the COVID-19 pandemic using system dynamics. They applied the SWARA methodology to assign weights to sustainability criteria and explored the impact of sustainability on the supply chain's resilience under various scenarios. The results demonstrated the impact of sustainability on the supply chain's resilience. The study conducted by Monin and Telukdarie (2021) investigates the impact of digitalization and localization of the supply chain in the dairy production industry on the supply chain's resilience using system dynamics.

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The results showed that digitalization and localization of the supply chain can lead to increased local employment and continuous improvement, while insufficient skills can moderate this effect. Another study was conducted by Olivares Aguilera and Almarakei (2021). The authors explored the resilience paradigm in the supply chain and presented a framework based on system dynamics to observe the behavior of the supply chain and assess the impact of disruptions and coping strategies.

The research conducted by Liu et al. in 2020 examined the construction supply chain for greening purposes, specifically focusing on building materials. For this purpose, they utilized system dynamics modeling and the Vensim software. The researchers concluded that China generates a significant amount of construction waste annually. However, they have also determined that with the implementation of appropriate measures, it is possible to control up to 50% of this waste. Rabs et al. (2019) conducted a comprehensive review regarding the application of system dynamics modeling in the fields of green supply chains and sustainable supply chains. They highlighted research gaps in this area. Another study was carried out by Kao et al. in 2019. A system dynamics model was presented to simulate scenarios for reducing CO2 production in China's coal-based electricity supply chain. They found that the most significant reduction in CO2 production can occur in the transportation system. They also proposed that the framework they provided could assist in greening the supply chain of other industries, including the supply chain for iron and steel production.

A further study was conducted by Jafarnejad et al. in 2019. They examined the dynamic relationships between resilience criteria in the medical equipment supply chain. Researchers first identified the criteria of interest using the fuzzy Delphi method and then evaluated their impact on the supply chain using four scenarios. In 2019, Saoudra et al. used a system dynamics approach to examine and review studies on renewable energy sources in the sustainable supply chain. This study highlighted the literature gaps in this area and identified various research topics for future researchers. The study conducted by Singh et al. in 2019 examined resilience in the supply chain of a soap manufacturing company in India. The findings of the study revealed seasonal demand pattern changes. Saeedi and Awasthi (2017) presented an integrated approach based on system dynamics and the Analytic Network Process (ANP) for evaluating sustainable transportation policies. The researchers used the ANP method to weigh and rank sustainable transportation policies in the supply chain and employed system dynamics to simulate the supply chain.

The review of previous studies has shown that the large-scale supply chain in the steel industry has received little attention from researchers, with most studies focusing on a single paradigm, such as resilience or sustainability in other industries. The present study emphasizes the paradigm of the large-scale supply chain in the steel industry, utilizing a system dynamics approach. It investigates different strategies for steel production and examines the impact of iron waste production and regional GDP on the steel industry.

Research Methodology

This research is practical as its results are applicable in the relevant industry. In terms of research design, this study is classified as a mixed-methods study (qualitative and quantitative). This classification is based on the fact that, in the initial phase of the research, qualitative data was drawn upon to identify variables related to the problem and clarify the relationships among them. Then, for analyzing the relationships and examining the dynamic behavior of the system, quantitative data and dynamic simulation were used, which is a quantitative approach. System dynamics modeling was employed for simulation using Vensim software. The systems dynamics approach in this research demonstrates the mutual influence of factors in a dynamic model. Moreover, it enables the determination of an appropriate dynamic model to expand the steel supply chain.

The most fundamental principle that system dynamics articulates is that feedback loops and delays shape the behavior of systems, and the dynamism of a system's behavior results from the system's underlying structure (Handayani et al., 2022).

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Research Model

In order to model, the variables affecting performance and decision-making in the steel industry supply chain are first presented, which include:

Table 1: Variables affecting the performance and decision-making in the steel industry supply chain

Production-related variables and production capacity	
Steel production rate from iron ore	The amount of steel that is extracted and produced from each unit of iron ore
Rate of steel production from waste	The amount of steel that is produced from each waste unit. This variable represents the efficiency of using waste and converting it into marketable products.
Processing capacity of iron ore	Ability to produce raw materials needed to produce steel from iron ore
Waste processing capacity	Ability to produce steel products from steel scrap or other recycled materials
Growth rate of production capacity of steel products	Increase in production capacity of steel production units. It indicates the rate at which the production capacity of steel products increases over a certain time frame, usually on an annual basis.
Delay of development of steel products production capacity	The time from the decision to increase production capacity to the actual start of new production. It also has effects such as reduced production, increased market volatility, increased opportunities lost, increased costs, and reduced competitiveness.
Minimum capacity of steel product production	The lowest volume of steel products produced by the manufacturer
Financial and Economic Variables	
GDP area	The total value of goods and services produced within a specific geographical area
Long-term demand for steel products	Estimation of the amount and type of demand for steel products in future periods.
Demand and market variables	
Demand for steel products in the market	The extent and number of steel products being purchased by customers, industries, and business contracts in a particular region or market. Various factors, such as economic growth, construction and infrastructure development, automotive industry, industrial equipment and machinery, changes in consumption model, and geographical and environmental factors, can affect the demand for steel products in the market.
Changes in customer tastes and needs	It refers to changes that occur in the mindset, tendencies, and preferences of customers in purchasing and consuming products and services, and factors such as changes in the life model and culture of consumption, technological changes, economic changes, environmental and sustainability, changes in needs and problems, and changes in competition and markets.
Competitors and competitive developments in the market	This variable refers to the creation of an active and dynamic competitive environment that includes other business partners in a given industry or market who are producing products or services similar to those of a particular company. This variable includes the entry of competitors into the market, changes in competitors' strength, changes in strategies and innovation, changes in pricing and marketing, and changes in the type and quality of products.
Technology and Innovation Variables	
Technological advances in	It refers to the improvement of processes, equipment, tools, and

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manufacturing and processing processes	techniques used in manufacturing industries.
Innovation in products and processes	Change and improvement refer to a new invention in products, services, processes, technologies, or business methods.

Below, dynamic system models related to the three steel production strategies mentioned in this study are presented:

Strategy One: Steel Production from Iron Ore
The delay in iron ore capacity development refers to the delay in the development and utilization of iron ore resources, which depends on various factors such as technical, financial, or economic challenges associated with the development and exploitation of iron ore mines. Additionally, long-term steel production estimates from iron ore are based on predictions and past experiences.

The development rate of iron ore processing capacity represents the rate at which the processing capacity of iron ore in production units is increasing, which determines the steel production potential from iron ore resources. The accumulated capacity of iron ore processing is also dependent on this rate and indicates the accumulation of processing capacity over time. The rate of capacity depreciation of iron ore processing is subtracted from the accumulated variable and reflects the amount of capacity reduction in iron ore processing due to various factors such as equipment breakdown or physical factors. The lifespan of iron ore processing facilities also has an impact on this rate, as well as the minimum capacity of iron ore processing and the rate of development of iron ore processing capacity. Various inputs, such as the iron ore input rate and the estimated required iron ore, also influence the iron ore processing capacity. These inputs are affected by the number of iron ore resources, the delay in iron ore development, the long-term estimation of steel production from iron ore, the estimation of regional raw steel demand, and the number of iron ore reserves. The variable of iron ore inventory accumulation is also considered in these interactions. The outflow in this section is the steel production rate from iron ore, which represents the amount of steel produced from iron ore resources. Furthermore, the flow of the iron ore scrap production rate in the region, which is influenced by the regional GDP and its growth rate, plays a crucial role in determining the economic impacts of this particular segment of the steel supply chain. This link serves as a connection to the subsequent part of the model.

Strategy Two: Steel Production from Scrap
This strategy focuses on steel production from steel scrap, aiming to utilize recycled materials for producing new steel and reduce the dependence on natural iron ore. It also contributes to environmental pollution reduction and conservation of natural resources. Additionally, it helps in minimizing waste and steel material disposal. Steel scrap refers to recycled materials obtained from the demolition of buildings, automobiles, and industrial waste in the steel industry. An increase in the region's GDP may lead to the improved purchasing power of the local population. Furthermore, it may increase construction projects and infrastructure development, which, in turn, require steel products. It can also attract industrial investments to the region. This investment may include establishing and developing steel production units, which would enhance production and employment. Consequently, an increase in the region's GDP can boost demand for steel products and, as a result, affect the production of these products.

Strategy Three: Accumulating Capacity for Steel Product Manufacturing
Strategy Three is based on increasing steel manufacturing capacity to meet higher market demands. The rate of capacity development for steel product manufacturing represents the speed at which the capacity for producing steel products expands over time and can be influenced by factors such as new equipment, advanced technologies, investments, and market demands. The delay in developing the capacity for steel product manufacturing represents the time required to develop and launch new production lines from the decision-making point. This delay can occur due to financial, technical, or other obstacles, resulting in delays in supplying steel products and a reduction in production capacity. The minimum capacity for steel product manufacturing indicates the minimum production capacity

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for steel products that can balance supply and demand in the market. Various factors can influence it, including market changes, price fluctuations, and other economic factors. As a whole, a delay in the development of steel product manufacturing capacity can lead to reduced production capacity, increased market fluctuations, and disruptions in the supply chain. It can also result in missed opportunities, contract violations, and decreased customer trust. This is in contrast to the depletion of production capacity, where, without capacity development, the inventory of steel products decreases, and the system faces shortages of products, leading to unmet market demand.

The relationships between the variables based on the three strategies outlined above are illustrated in Figure (1).

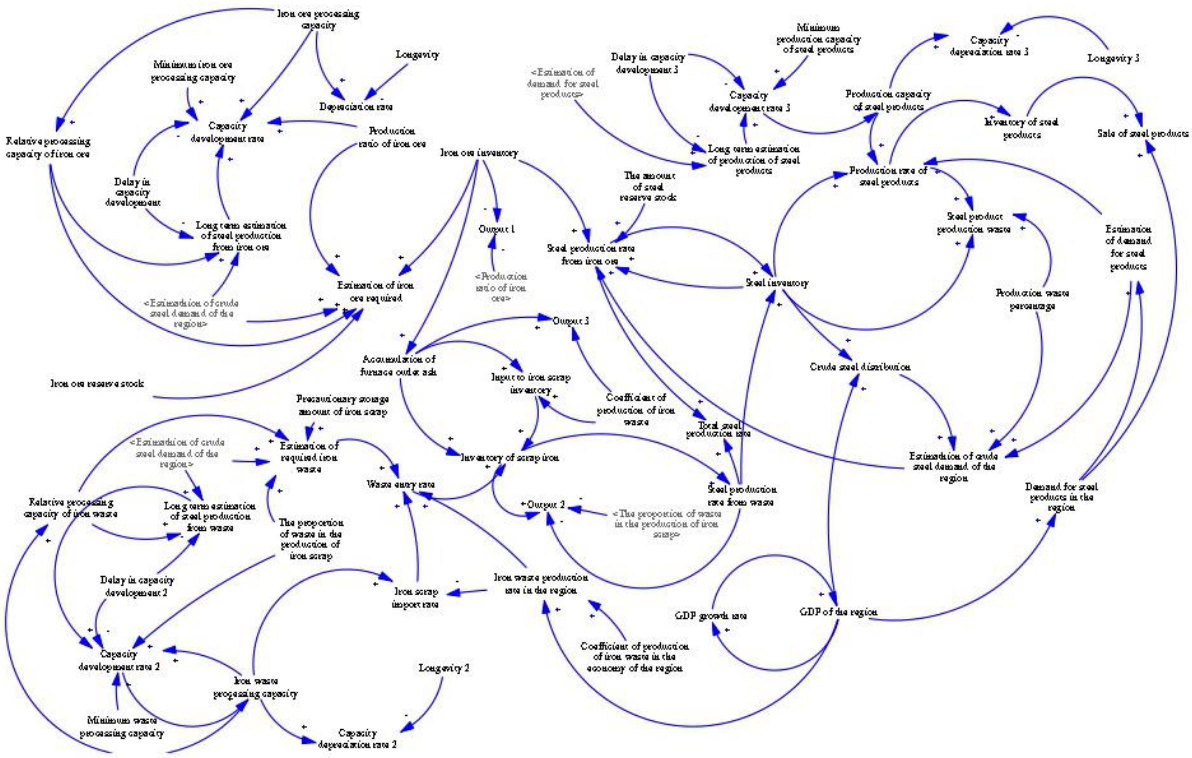
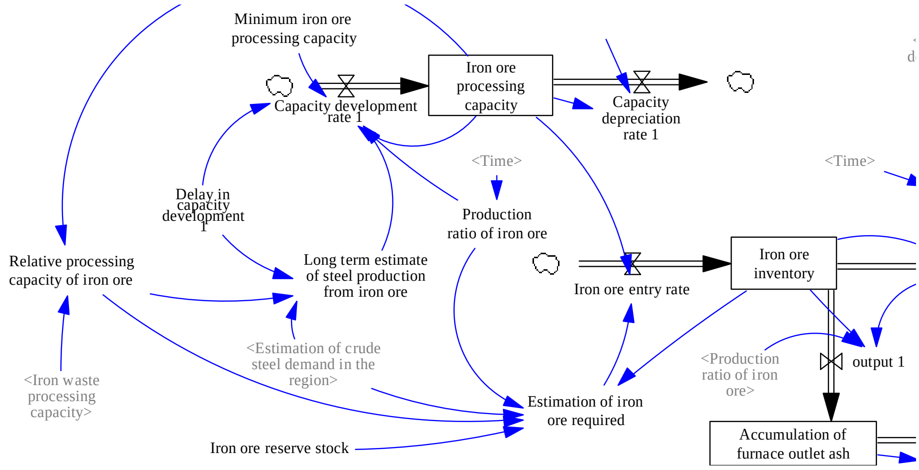


Figure 1: Causal Loop Diagram Based on the Three Strategies

The causal loop diagram above is based on three main strategies for producing steel from iron ore and steel scrap. In this model, decision-making variables include minimum iron ore processing capacity, iron ore development delay, long-term estimation of steel production from iron ore, iron ore processing capacity development rate, and the depreciation rate of iron ore processing capacity. These variables influence input variables such as iron ore input rate, estimated required iron ore, output flow from the furnace, waste from steel product production, estimated demand for steel products, and raw steel distribution. Additionally, input variables such as demand for steel products and regional GDP also affect output variables, including the rate of steel product production. By examining the mutual effects of these variables, the model illustrates complex and dynamic relationships in the supply chain of the LARG steel industry in Yazd. Understanding these interrelationships is highly significant for optimizing production processes and supply chain management in this industry.

Moreover, decision-making variables such as the estimation of demand for steel products and raw steel distribution also impact the rate of steel product production. Increases or decreases in these variables can lead to changes in the rate of steel production and other output flows. The causal loop model assists managers and decision-makers in the steel industry of Yazd by optimizing production strategies, inventory management, and supply chain planning in response to market fluctuations and various environmental variables. This is achieved by considering these variables' increasing or decreasing effects on each other. By revealing the complex relationships between variables, this dynamic model highlights the strengths and weaknesses in the steel supply chain, enabling the



provision of more effective optimizations in production and supply processes. Additionally, flow accumulation diagrams related to the three strategies are presented in Figures (2), (3), and (4), respectively.

Figure 2: Steel Production from Iron Ore

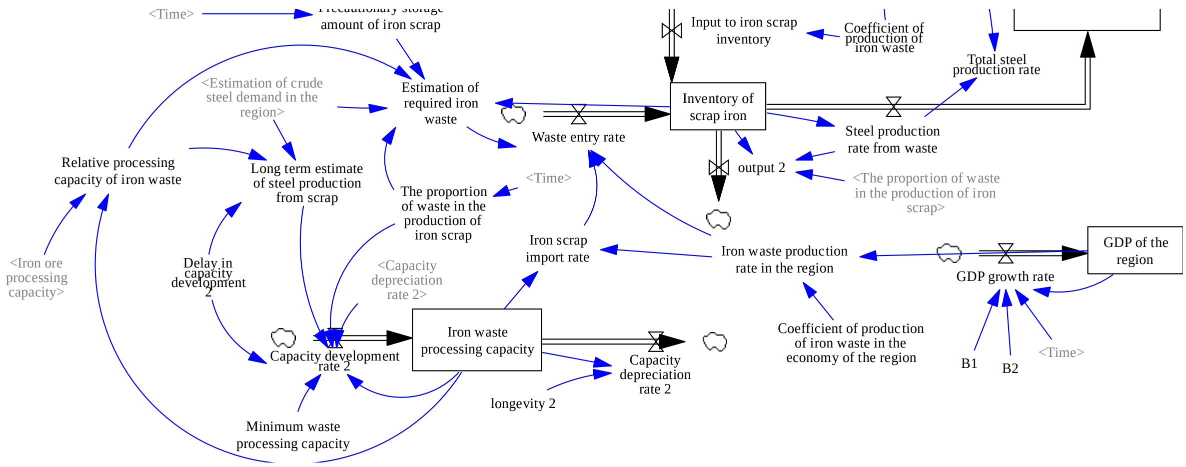


Figure 3: Steel Production from Scrap

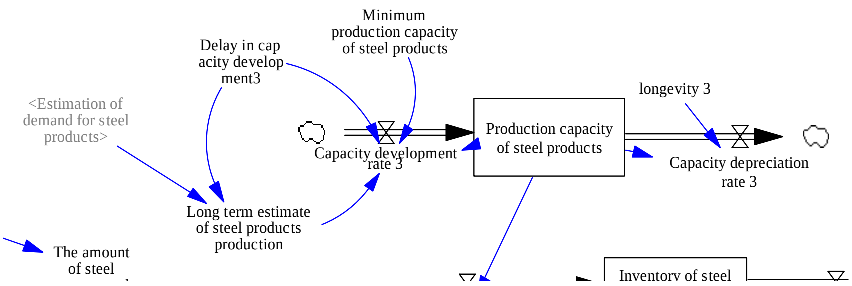


Figure 4: Steel Products Manufacturing

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In this model, the concept of 'purity' is derived using four variables: the desired ratio of scrap from production, the ratio of scrap from production, the ratio of scrap to the sales of steel products, and the desired ratio of scrap from sales, as presented in Figure 4. Additionally, agility in the supply chain model refers to the ability to adapt more quickly and flexibly to changes and different conditions (Ahmad et al., 2021). In this model, the introduction of the variable 'Accuracy of Raw Steel Demand Estimation' as a more accurate measure for raw steel demand was examined for adaptability and flexibility to changes, as presented in Figure 4.

In the model, resilience is examined by defining three main variables:
1. Steel Inventory Resilience: This variable represents the supply chain's ability to manage and maintain steel inventory in the face of demand and supply changes. It indicates the supply chain's capability to tolerate market fluctuations and perform well in various conditions.
2. Iron Ore Inventory Resilience: This variable demonstrates the supply chain's strength in preserving iron ore inventory against changes in steel supply and production. It signifies the supply chain's capacity to withstand fluctuations in iron ore inventory and optimize performance.
3. Iron Waste Inventory Resilience: This variable indicates the supply chain's ability to manage iron waste inventory in the face of various changes and fluctuations. It represents the supply chain's capacity to handle risks related to waste and resource efficiency.

Overall Research Model

By combining the three mentioned strategies and considering the interaction of various variables in the LARG supply chain in the steel industry of Yazd, the proposed model was developed, as depicted in Figure (5). This allows managers and decision-makers to implement various improvements in the supply chain and enhance the overall performance of the supply chain. Taking into account the interactive effects of various variables, this model can serve as a powerful tool in strategic decision-making and supply chain optimization.

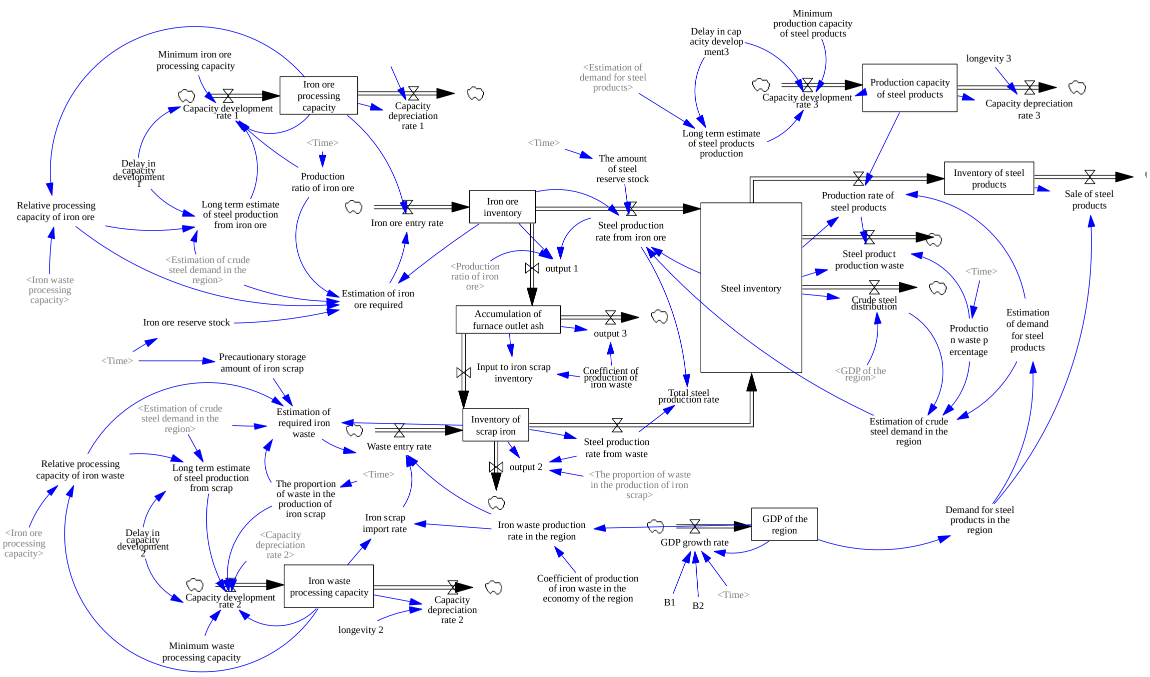

Figure 5: The Proposed Steel Production Model

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Data Analysis

As a primary starting point for evaluating the model's performance, the supply chain is considered under normal conditions, and the model is simulated based on the base scenario. This scenario serves as a basis for comparing the model's performance in optimistic and pessimistic scenarios. The simulation results of the base scenario are presented in Figure (6).

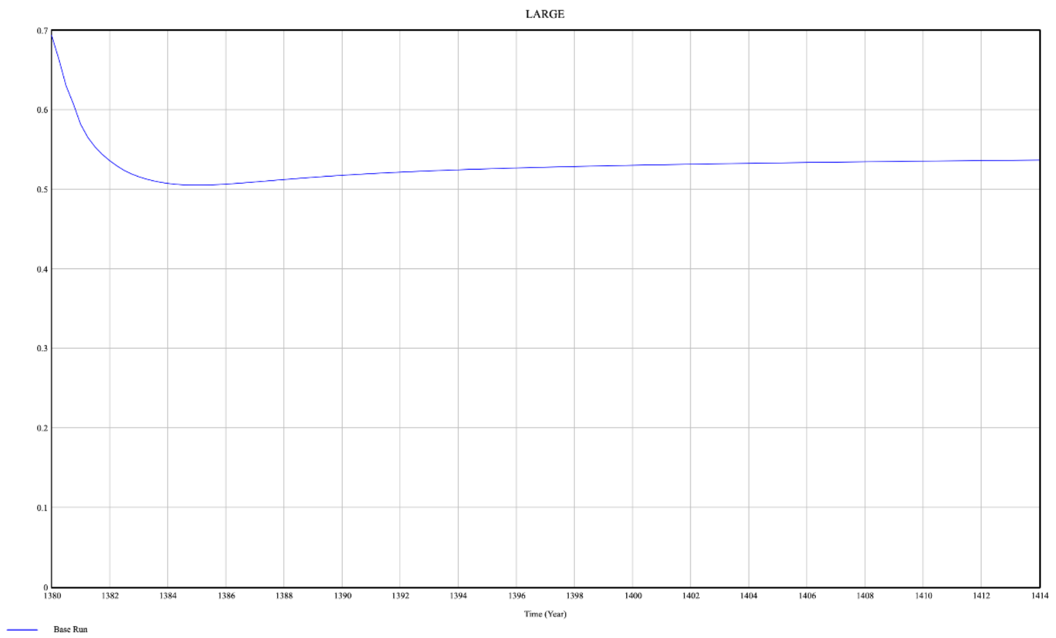

Figure 6: Simulation Results in Base Scenario Implementation

For model validation, variables with historical data were considered. These variables include items such as regional GDP, demand for steel products in the region, raw steel distribution, and production waste of steel products. By comparing the graphs and lines related to historical data with those related to the base model's execution, it can be ensured that the model has accurately estimated the real changes and trends in these variables. The validation results are presented in Figures (7) to (10):

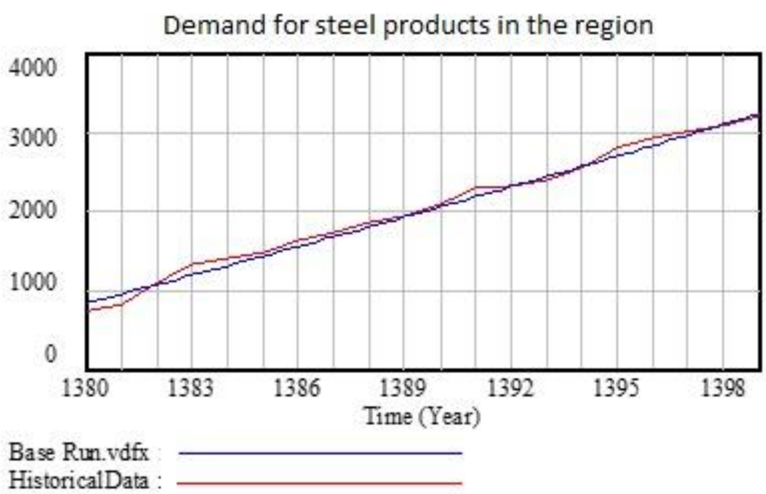

Figure 7: Demand for Steel Products in the Region

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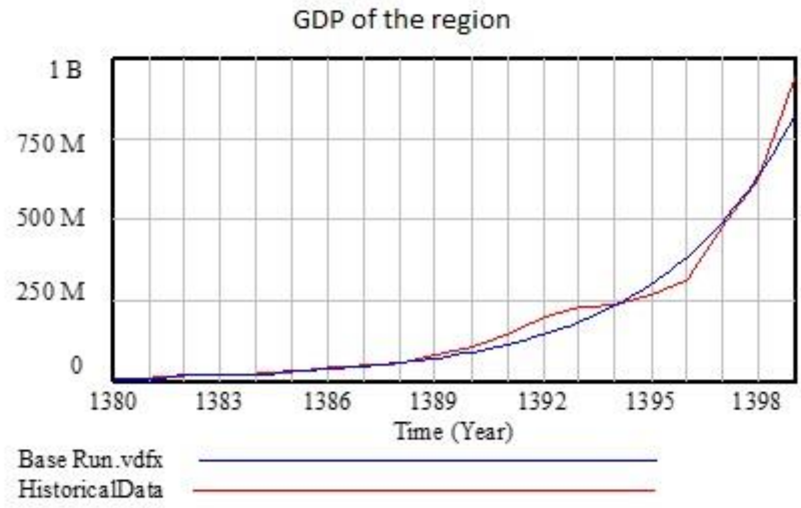

Figure 8: GDP of the Region

Figure 9: Steel Product Production Waste

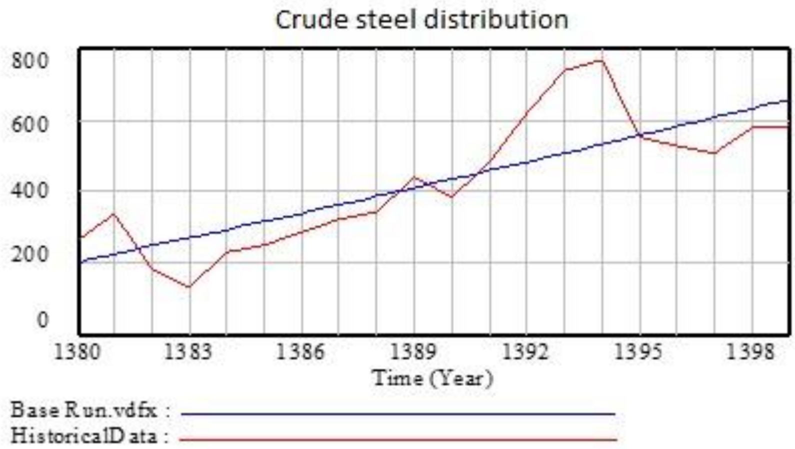

Figure 10: Distribution of Raw Steel

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Analysis of Sensitivity: Iron Ore Processing Capacity
In the pessimistic scenario for the iron ore processing capacity, it is observed that the producer is forced to increase capacity development with an increase in waste in the production process in order to maintain the previous production levels. This increase in development leads to further environmental degradation, ultimately reducing the sustainability and green aspect of the system, thus reducing the largness of the supply chain. Overall, this indicates that in pessimistic conditions, neglecting environmental preservation and further development in decision-making may lead to a decrease in the quality and overall sustainability of the system.

Total Steel Production Rate
In the optimistic scenario, variables such as the waste ratio in production from iron scrap, the production ratio from iron ore, the percentage of production waste, and iron ore reserves all increase on average. These positive changes lead to an increase in the total steel production rate because an increased production ratio from iron ore implies better utilization and higher efficiency of existing resources in production.

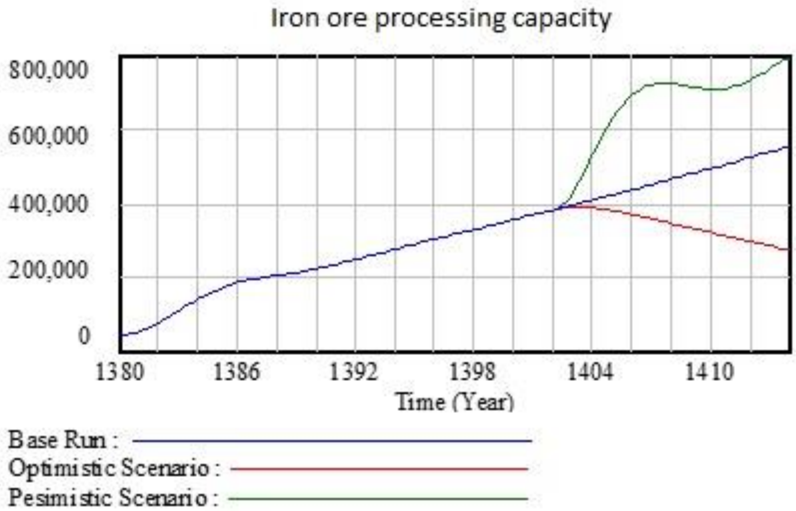

Figure 11: Iron Ore Processing Capacity

Moreover, an increase in the waste ratio in production from iron scrap implies an improvement in the process of converting waste into steel products and better utilization of available materials. A reduction in the percentage of production waste also leads to greater efficiency in production and resource conservation. An increase in iron ore reserves ensures an adequate supply of raw materials and production stability. In the pessimistic scenario, on the other hand, the mentioned variables decrease on average. These negative changes lead to a lower steel production rate. In summary, in the optimistic scenario, improvements in the changes of these variables result in an increase in the steel production rate, while in the pessimistic scenario, negative changes in these variables lead to a decrease in the production rate, as seen in Figure (12).

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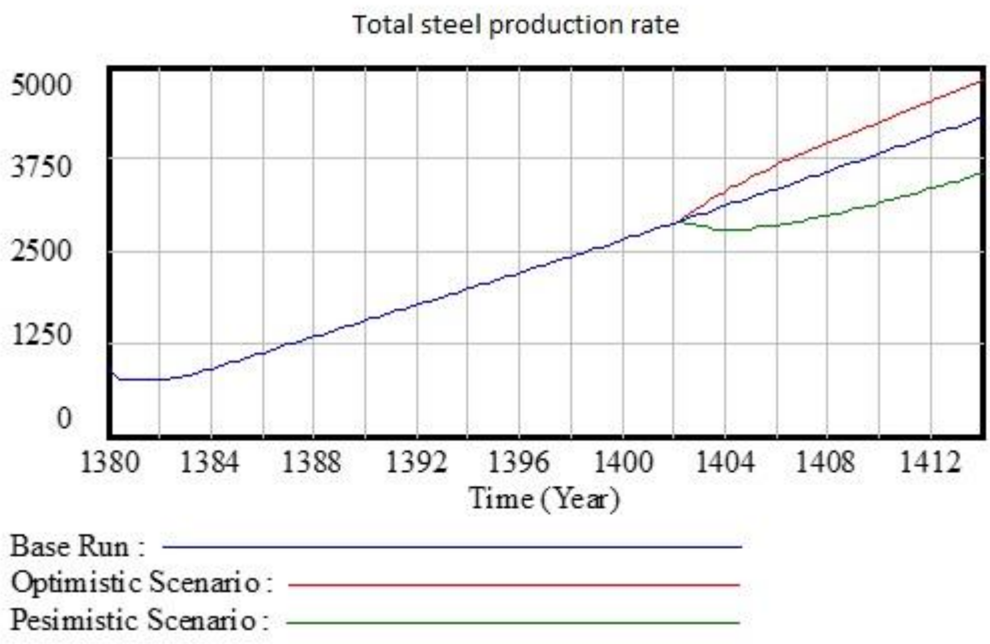

Figure 12: Total Steel Production Rate

Resilience Sensitivity Analysis
In the optimistic scenario, the graph shifts upward as the values of the variables increase, including such variables as the ratio of scrap in production, the ratio of production from iron ore, the percentage of production waste, and iron ore reserves. This indicates an improvement in resilience and, consequently, the largness of the supply chain in this scenario. In the pessimistic scenario, as the values of these variables decrease, the graph shifts downward, indicating a decrease in resilience and, consequently, the largness of the supply chain. In general, changes in the values of variables such as the ratio of scrap in production, the ratio of production from iron ore, the percentage of production waste, and iron ore reserves can be factors that lead to an increase or decrease in resilience in the steel industry, as seen in Figure (13).

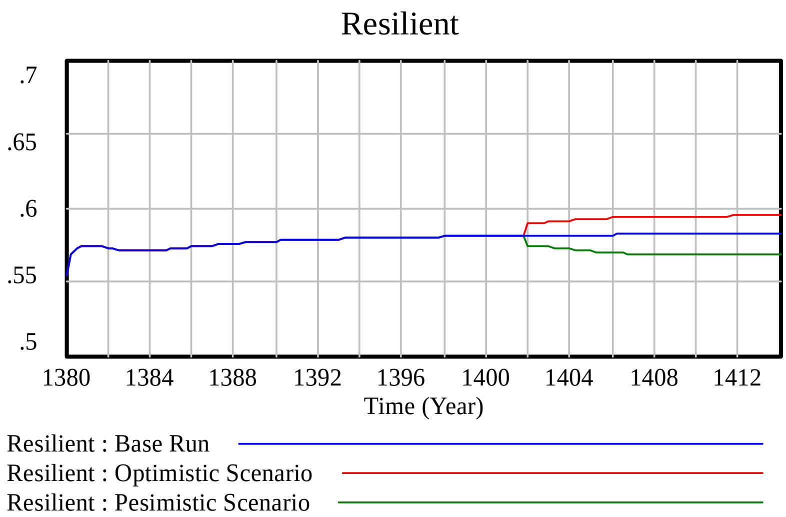

Figure 13: Resilience Sensitivity Analysis

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Lean Sensitivity Analysis

In an optimistic scenario, with the increase in the values of the scrap-to-production ratio of iron until 1402 (Iranian calendar year; March 2023) and positive changes in other variables, the production capacity from iron scrap increases. This improvement in the production capacity from iron scrap can indicate an enhancement in production efficiency and supply chain productivity. Furthermore, with the increase in the ratio of production from iron ore until 1402 (March 2023) and a decrease in the percentage of production waste along with an increase in iron ore reserves, it becomes evident that production from primary resources is done more efficiently and with higher quality, leading to increased efficiency.

In a pessimistic scenario, with the decrease in the values of variables related to production from iron scrap until 1402 (March 2023) and negative changes in other variables, the production capacity from iron scrap decreases. This reduction can indicate limitations or deficiencies in the production process and a decline in supply chain efficiency. Furthermore, the decline in the iron ore production ratio until March 2023, coupled with an increase in production waste percentage and a decrease in iron ore reserves, could potentially have a detrimental effect on the quality and efficiency of production. Accordingly, in the sensitivity analysis chart, considering the positive or negative changes in various variables, the resilient supply chain improves in the optimistic scenario, while it decreases in the pessimistic scenario, as shown in Figure 14:

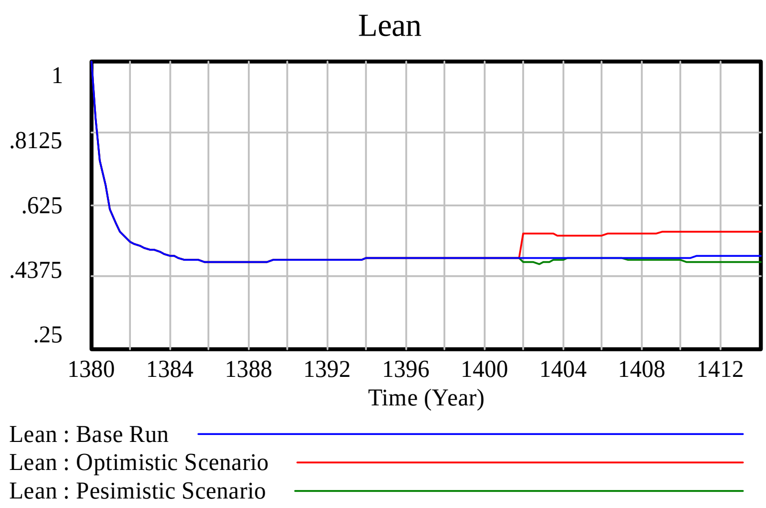

Figure 14: Lean Sensitivity Analysis

Agility Sensitivity Analysis

The optimistic scenario entails several changes that contribute to an enhancement in production quality and efficiency. These include an increase in the proportion of scrap in production derived from iron scrap (from 90% to 95%), an increase in the proportion of production from iron ore (from 0.013 to 0.03), a reduction in the percentage of production waste (from 0.095 to 0.08), and an expansion of the iron ore reserve from 0.03 to 0.045%. These improvements, especially in areas such as production efficiency, inventory management, waste reduction, and production capacity increase, are evident. Therefore, in the sensitivity analysis chart of the optimistic scenario, we will see an increase in the resilience and flexibility of the agile supply chain. This means that the improved supply chain will be ready to respond to environmental changes and new conditions.

In the pessimistic scenario, assuming a decrease in the proportion of scrap in production from iron scrap (from 90% to 85%), a decrease in the proportion of production from iron ore (from 0.013 to 0.01), an increase in the percentage of production waste (from 0.095 to 0.1), and a decrease in the reserve of iron ore (from 0.03 to 0.025) can indicate potential shortcomings and constraints in the supply chain, leading to reduced efficiency and quality of production.

In the pessimistic scenario, as shown in the sensitivity analysis chart, we can observe that the resilience and flexibility of the agile supply chain have decreased, and the supply chain is more vulnerable to environmental changes and adverse conditions. This is depicted in Figure (15).

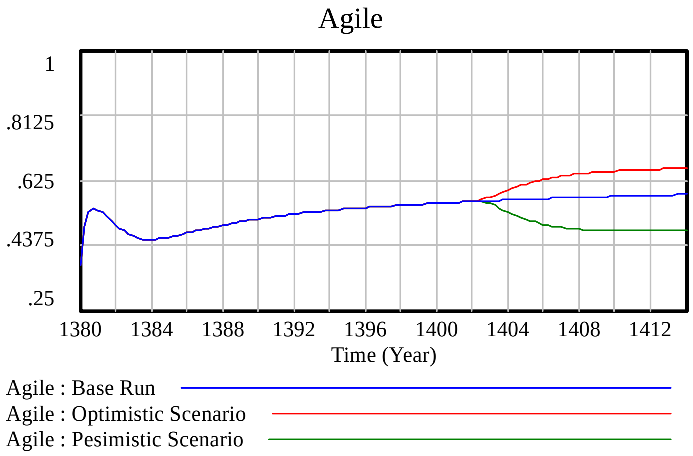

Figure 15: Agility Sensitivity Analysis

Greenness Sensitivity Analysis

In the optimistic scenario, considering the introduced definitions, an increase in the ratio of waste recycling to 95% by 1402 (March 2023), an increase in the ratio of production from iron ore, a reduction in the percentage of production waste, and an increase in the reserve of iron ore can lead to an improvement in the greenness of the supply chain. In the pessimistic scenario, the opposite changes in these variables will lead to a decrease in the greenness of the supply chain, as indicated by the sensitivity analysis chart in Figure (16).

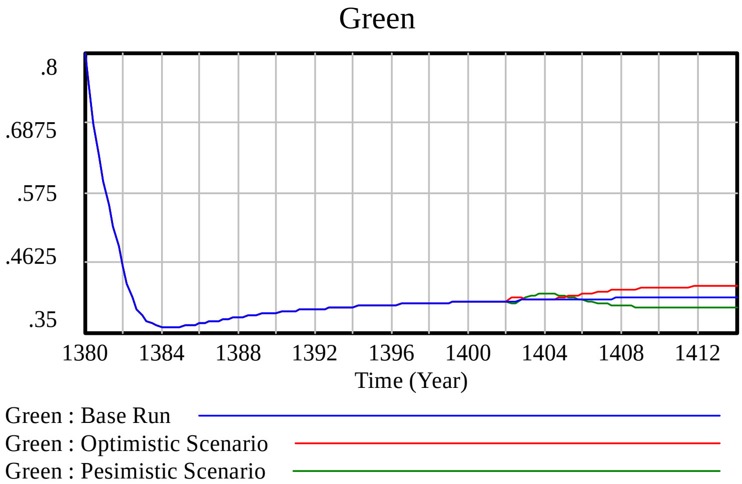

Figure 16: Greenness Sensitivity Analysis

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LARG Sensitivity Analysis

In the optimistic scenario, as described, increased sustainability, agility, greenness, and resilience can enhance the largness of the supply chain, while lower levels of these factors can reduce the largness of the supply chain. The results are shown in Figure 17:

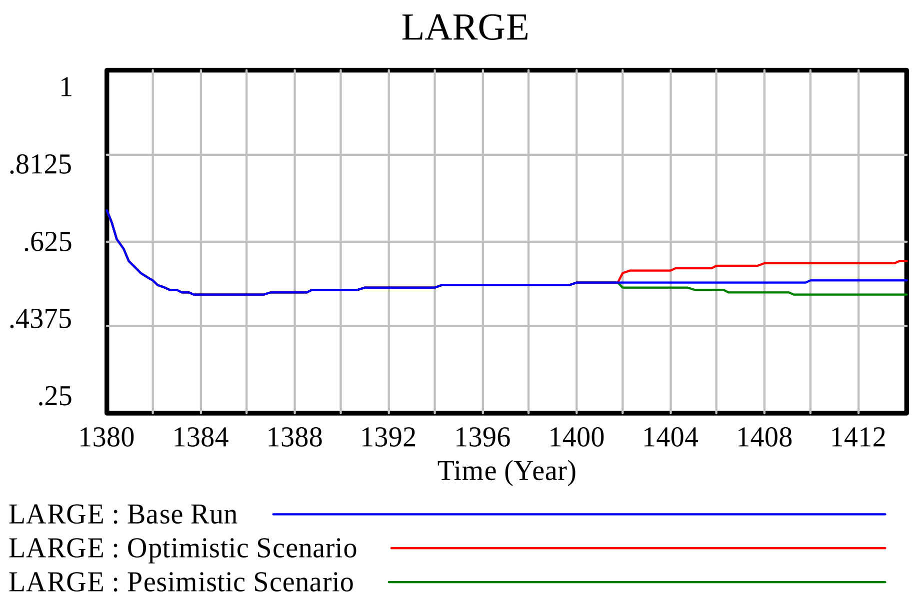

Figure 17: LARG Sensitivity Analysis

Conclusion and Recommendations

The results of this study demonstrate that the LARG Supply Chain Model can predict and interpret real-world conditions. Validation reveals that the model can reasonably describe the trends of supply chain changes. Sensitivity analysis also indicates that changes in key variables significantly impact the supply chain's performance. By altering the values of these variables, the supply chain's performance can either improve or weaken. This research provides decision-makers and managers in the steel industry in Yazd with an effective tool for enhancing and optimizing the supply chain in the face of challenges and environmental changes.

By utilizing this model and the analyses conducted, it is possible to attain sustainable growth and improve resource management in this industry. It enables strategic decision-making and management optimization when facing different changes. The model's validation results demonstrate its capability to effectively describe and predict changes in the supply chain of the steel industry. This validation indicates the model's ability to generalize to real-world conditions in the industry. The sensitivity analysis of the model's variables in two scenarios, optimistic and pessimistic, has shown that changes in the variables related to production from iron scraps, production from iron ore, the percentage of production from waste, and iron ore reserves have a direct and significant impact on the resilience, agility, greenness, and robustness of the supply chain. In the optimistic scenario, an increase in these values leads to improved supply chain performance. In the pessimistic scenario, a decrease in these values results in a weaker supply chain performance.

As a whole, this research highlights the importance and added value of the dynamic LARG supply chain model in enhancing and optimizing the performance of the supply chain in Yazd's steel industry. The analyses and results obtained from this research help decision-makers and managers in this industry optimize the sustainability and performance of the supply chain in their strategic and managerial decisions and cope with various changes in the business environment.

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It is recommended to utilize advanced technologies efficiently, optimize existing equipment and resources, and increase their efficiency. For example, it is possible to increase output within the existing capacity by employing advanced production methods, improving product quality, and reducing waste. Upgrading the technologies in use can create new capacities with high efficiency and longer lifespans. This entails an increase in production capacity and supply chain sustainability, resulting in reduced environmental impact and lower investments. Ultimately, it leads to a higher level of supply chain largness.

For future research, it is recommended to determine the weights of variables and strategies used in the model using decision-making methods. Additionally, the impact of information technology on supply chain largness can be investigated within the model.

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