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Designing a Model and Simulating the Production Chain of the Metal Industries in a System Dynamics Approach (Case Study: Shablon Tajhiz Company)

Farzad Amiri[a]*

[a] *Department of Industrial Engineering, Faculty of Engineering Management, Kermanshah University of Technology, Kermanshah, Iran.*

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ABSTRACT

The supply chain includes all the activities required to deliver a product or service to end customers. By adopting the above approach to the supply chain, production and distribution functions are added to the chain as part of the flow of goods and services. The supply chain in this approach includes three areas: procurement, production, and distribution. This article results from a research project commissioned by the Kermanshah Industry, Mining, and Trade Organization to improve the production capacity of metal industries in the province. Based on this, effective loops were identified with the initial introduction of 26 selected companies active in the province and conducting several rounds of interviews with the management and experts of these companies. With the suggestion of the Industry, Mining, and Trade Organization and with the agreement and participation of the best and most complete company active in this context (Shablon Tajhiz), it was modeled and executed. The formulation was designed with the participation of the panel of experts and in the form of discussion sessions based on the trial and error method. In order to confirm the results, the statistical data of the company was extracted from 1390 and compared and validated with the results obtained from the model's output. Since the nature of these loops and their constituent variables change over time in the actual state. A dynamic systems approach has been used to simulate the model and consider dynamic conditions and their mutual effects. The structure of the results was checked and confirmed through the sensitivity analysis of the findings. It is worth mentioning that the analysis and drawing of the results were done using Vensim software.

Keywords

Model design, Production chain simulation, Metal industries, System Dynamics, Missing loops.

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*Corresponding author
Email: f.amiri@kut.ac.ir

1. Introduction

During the 1960s and 1970s, organizations were trying to increase their competitive power by standardizing and improving their internal processes to come up with products featuring better qualities and lower costs. At that time, the prevalent thought was that strong engineering, designing, and coherent and coordinated operations were prerequisites for attaining market demands and acquiring a larger market share. For the same reason, organizations direct all their efforts toward increasing efficiency. It did not take them too much time before they became aware of the reality that mere attention to production and technology cannot guarantee the success of the manufacturing companies and factories; thus, their gradual move towards the other factors influencing the production cycle was placed atop of the companies' agenda. This critical issue became the prelude to forming an important concept named supply chain management (Soori et al., 2023). The supply chain encompasses all the activities related to the goods flow and materials conversion, from the procurement of the raw material to the delivery of the final goods to the customer, planning, and management of the demand and supply, preparation of materials, service, or goods production and scheduling, warehousing, inventory control and distribution, delivery and service to the customer (Asha et al., 2023).

Some have limited supply chains to the relationships between the buyer and seller, and this approach is only concentrated on the first order purchase operation in an organization. Another group adopts a broader approach to the supply chain and considers it to include all of an organization's supply sources. With this definition, the supply chain includes all the first, second, third, and higher rank suppliers. Such an approach towards the supply chain includes all the activities required to offer a product or service to the final customer. With the approach mentioned above towards the supply chain, the manufacturing and distribution functions are added as part of the goods and services flow to the chain. In this perspective, the supply chain embraces three areas: provisioning, production, and distribution. Although supply chains are used in manufacturing and service organizations, the chain's complexity may vary significantly from one industry to another and from one company to another (Shehzad et al., 2020).

The supply chain is comprised of the following five essential principles indicating its importance (Osborne and Dempsey, 2023):

- Connectivity
- Collaboration
- Synchronization
- Leverage
- Scalability

The supply chain is a set of factors that create added economic value. The incorrect performance of this chain disrupts the creation of added value at the macroeconomic level. Although the "production chain" in the project title is meant in a macro way, since the effective factors in forming the production chain are placed inside a package, the main focus in the future sections will be directed toward the supply chain. In a systematic approach, the production chain forms the supply chain network as part of the supply chain loop (Ni and Sun, 2019).

2. Method

According to the research classifications, the present study's modeling is a developmental and applied type because data have been collected from a manufacturing-distributive business entity besides employing the system dynamics technique, and improvement policies are being presented for it. Moreover, considering the nature of the issue investigated in the present study, a dynamic approach of the qualitative-quantitative type will be adopted for the system. The present study will apply diverse library research methods, field studies, questionnaires, interviews, and dynamic modeling based on the needs. For performing data analysis, Vensim Ple 6.1 Software's capabilities will be utilized to draw policy analysis diagrams and investigate the model's structure. The behavioral pattern of the model's parts will be analyzed by investigating the possible scenarios. Deep semi-structured interviews will be conducted with the addressees in the field investigations. The interviewees have been selected regarding each of the production sectors from amongst the industry owners, executives (private sector), employees and experts of manufacturing entities, state sector specialists in the area of the industry, and professors of the universities. The methods used for gathering information required by the study are as follows:

(1) Statistical methods
(2) Library research (reference to articles, researches, dissertations, reports and so forth)
(3) Field study (interview)
(4) Holding brainstorming sessions and forums

2.1. The Study population, sampling method and sample volume calculation

The project executive(s) were the managers and experts of the manufacturing businesses (metal industries' sector of Kermanshah Province) and managers and specialists of the policy-making (governmental) sector. Sampling was conducted purposively and from amongst the identified addressees. Thus, the sample volume pattern was not found applicable in this regard.

2.2. Study objectives

(1) Designing a model and simulating the production chain in the metal industries with an approach to a system dynamics
(2) Determining and suggesting the missing links affecting the model
(3) Predicting the behaviors of the production model's essential variables (provincial metal industries)

2.3. The supply chain

It is a network of organizations involved in processes and activities based on top-to-bottom relationships. It creates value through products and services provided to end customers. Everyone working in the supply chain aims to increase competition or improve customer service levels. Today, from the point of view of final customers, an organizational unit alone is not responsible for the competitiveness of products or services, and the customer considers the supply chain of the entire organization at once. The competition of companies has been drawn towards supply chains, based on which activities such as supply and demand planning, material procurement, product production and programming, goods storage services, inventory control, distribution, delivery, and customer service at the level now the company is moving towards the supply chain level (Soori et al., 2023). A supply chain generally includes all parts that directly or indirectly contribute to meeting customers' needs. The supply chain does not only include suppliers and manufacturers, but in addition to the transportation sector, wholesalers, retailers, and even their customers are also other components of the chain (De Giovanni and Vinzi, 2012).

The industrial supply chain should be considered as a set of supply chains related to a specific industry in an industrial area and parallel to the integration of various supply activities required by each component of the entire extended chain and communication flows. (Engelseth et al., 2019). These links must be in the product supply chain to complete the supply process. However, because of their absence, the produced in the background of the supply chain must be sent outside the industrial area to experience more value. It adds processes and then returns to the industrial area. The absence of these rings, like the presence of critical rings, reduces its cost-effectiveness due to the scale and spatial limitations of the industrial area.

The increasing competitiveness or the very elevation of service-providing to the customers because, nowadays, from the perspective of the final customers, an organizational unit is not alone responsible for the competitiveness of the products or services, and it considers the supply

chain of the whole organization all at once. The companies' competition has been dragged towards the supply chains, based on which activities like planning demand and supply, material procurement, product manufacturing and programming, goods maintenance services, inventory control, distribution, delivery, and service to the customers were all previously carried out in the company level are now being transferred to the supply chain level (Soori et al., 2023). Generally, a supply chain includes all the parts directly or indirectly engaged in completing the customers' needs. The supply chain does not solely incorporate the suppliers and producers. Instead, besides the transportation sectors, wholesalers, retailers, and even their customers are among the other components of the chain (De Giovanni and Vinzi, 2012).

An industrial supply chain should be considered as a collection of supply chains related to a specific industry, located inside an industrial region and working parallel to the integration of the various supplying activities needed by each component of the whole wide chain as well as the connective flows related to them (Engelseth et al., 2019). The product supply chain loops were necessary to finish the supply process. However, due to their absence, the product manufactured in the backend of the supply chain has to be sent outside the industrial district to undergo the subsequent value-adding processes and transferred back to the industrial region afterward. The absence of these loops, like the existence of critical loops, mitigates the cost-effectiveness stemming from scale and the spatial constraints of the industrial region.

The most important result of this research is the identification of excess, missing, and critical capacities in this industry, which requires decisions such as planning the export of products in the loops leading to excess capacity and completing the capacities of critical loops by improving the situation. The quality and quantity of these links are controlled through various incentives and licenses to design, develop, and create missing links (Chari et al., 2022).

2.4. System dynamics

Dynamics of the system is an evaluation method for increasing learning in the area of complex systems as well as a method for perceiving the intricacy of system dynamics and designing effective policies. Recording and investigating the critical functional points of the systems is one of the best ways of organizing the correct and rapid reactions to the issues related to the systems; it takes the form of a prospective scenario that takes as its criterion the past and the present behavior of the system's environment. Recording this scenario entails applying the knowledge and technique that correctly identifies the problem by taking advantage of a systematic method and presenting the fastest and most proper reaction to overcome the created

challenges. This knowledge is called system dynamics (Lai and Nagarajaiah, 2019).

2.5. The variables interrelationships

Some of the model's critical key relations have been obtained from "if-then" functions, "reference models" and "time delays" that have been pointed out in Table 1.

Table 1. Main equations.

ID	Name	Type	Formula/Amount
1	Missed sales	State	M.S = (0.9) * (Sh)
2	Income	Auxiliary	I = S * (S.Pri) - (M.S) - (Vat)
3	Cost of advertisement and marketing	Auxiliary	A.M.C = (0.01) * (I)
4	Product demand	Level	P.D = (1000) * (A.M.C) / (S.Pri)
5	Shortage	Auxiliary	Sh = (P.D) - (P.V)
6	Sales	Auxiliary	S = Rcos * Pv
7	Missed sales: stock/demand	Auxiliary	M.S = 0.9 * St / D
8	Working capital	Auxiliary	W.Ca = I + F.E.I + B + B.F + Int.B.R
9	Production potential	Auxiliary	P.Po = Rco P.Po * W.Ca
10	Development of industrial units	Auxiliary	DEV.IU = P.Po + E.Ma + O.p + R&D + P.D + Em.mo
11	Effective management	Auxiliary	E.Ma = Po.Man + In.Fea + Ma.rB + Ma.rIn&Tax + Ma.rW + Ma.rTra
12	Quantitative development of industrial units	Auxiliary	Quan.DEV.IU = Rco Quan.DEV.IU * DEV.IU
13	Production volume	Level	P.V = (P.CA + R.M.D) * P.Te
14	Human workforce potential	Auxiliary	Po.Man = (Tr * A.E.H.R) + W.Ca

[1] Source: Study findings.

3. Fundings

3.1. Causal loop diagram of industrial production chain

Various variables can influence the performance of metal industries' production chains, hence the functioning of metal industries. Thus, the system dynamics method has been utilized to analyze and investigate how these variables improve the performance of metal industries' production chains. In order to achieve this, the relevant variables were first gathered, and Figure 1's Causal loop diagram for this model was created.

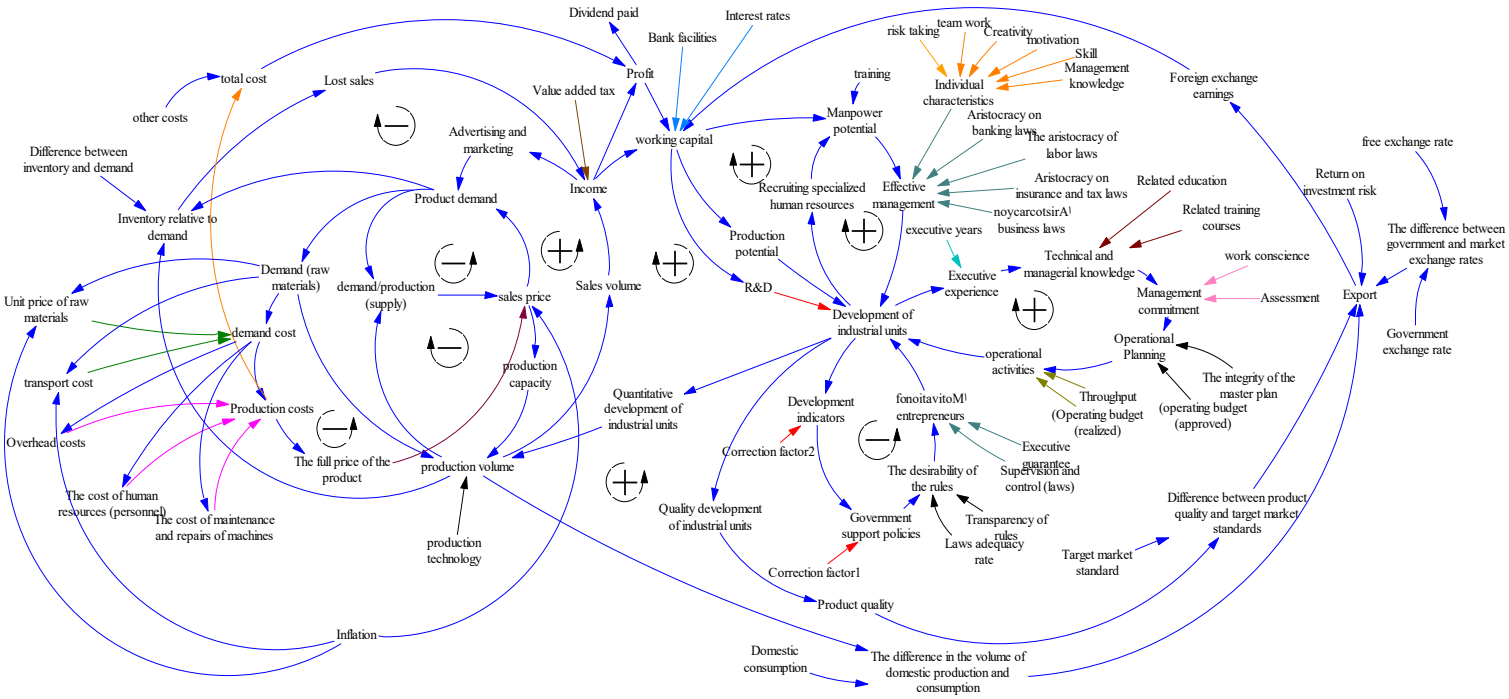

Figure 1. Causal loop diagram for the effect of the related variables on the production chain of the metal industries in provincial level.

3.2. Stock and flow diagram

The relevant stock and flow diagram is drawn and simulated based on the related causal loop diagrams. Figure 2 illustrates the stock and flow diagram related to identifying the missing loops in the metal industries' production chain in Kermanshah Province.

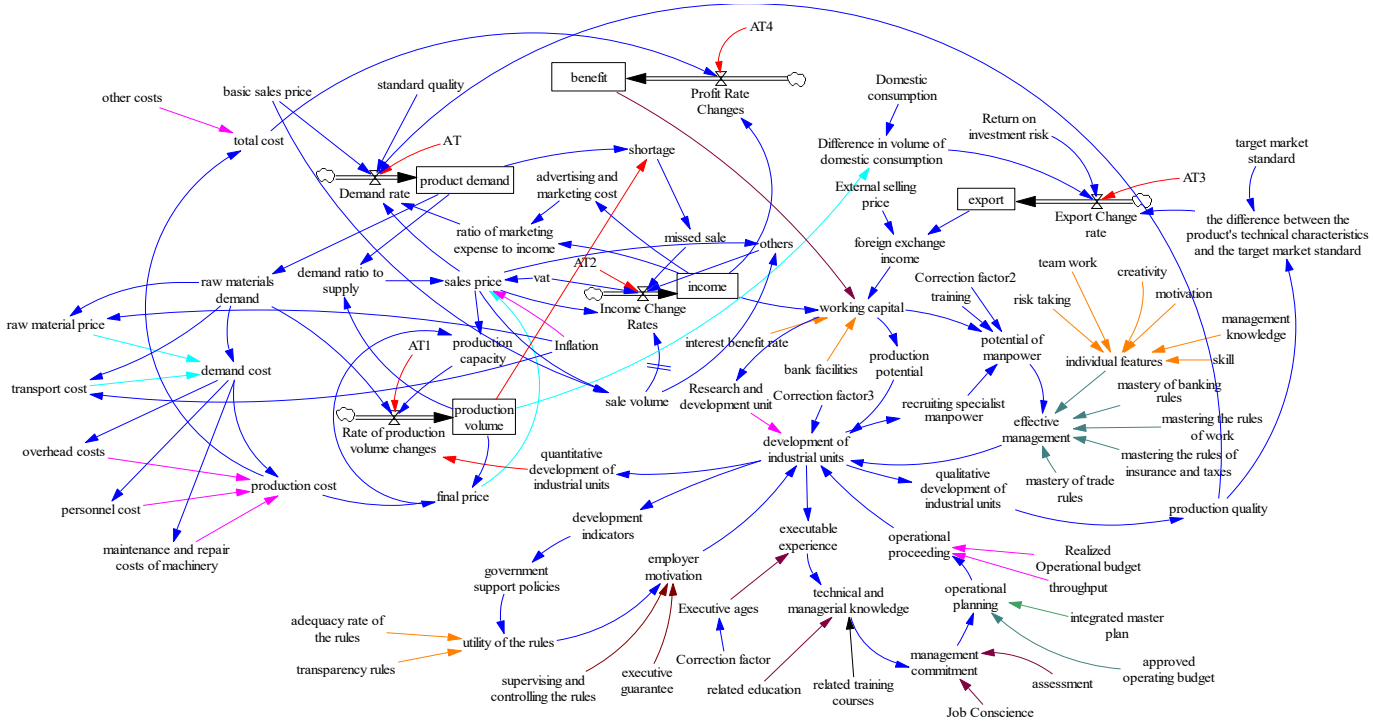

Figure 2. Stock and flow diagram for identifying the missing loops of the metal industries' production chain in Kermanshah Province.

Implementing the Simulation Model of Metal Industries' Supply Chain in Kermanshah Province.

After inserting numbers in the model and writing the functions and equations, the model is correctly implemented, and the diagram of some of the model's accumulations takes the following form after a stage of execution:

3.2.1. Analysing the behaviour of sale price and product demand in the model

Undoubtedly, one of the most critical concerns of the persons involved in the industry is predicting and properly understanding the variables influencing future business development (Loxton et al., 2020). The product's sale price(goods price) is among these variables. By correct prediction of the contingent sale price with a suitable risk, the business income flow can be computed during the future years. In line with this, the importance of the product price in the sustainability of the business is dealt with in the analysis and prediction of this variable's effect on the future behavior of the model. It is evident that the sale price of the product is a function of many indicators, and, naturally, the investigation of all these factors would cause complexity of the issue and increase the risk of improper identification, making it rather infeasible. However, using the Pareto analysis (20-80 rule), It is evident that the selling price is influenced by the ratio of product supply to demand on the one hand and, on the other hand, by the cost price (Aslam et al., 2021). It is evident that inflation also influences the sale price and annually increases it. The potential demand is reduced with the relative increase in the product price that would, per se, cause a reduction in the product supply-to-demand ratio, eventually causing a reduction in the price growth gradient (acceleration). In other words, the price increases will face a reduction in the growth gradient concerning a prior state (Ghasemzadeh et al., 2021). It is worth mentioning that in the evaluation of the behavior of the model, due to the necessity of conducting long-term research on the variables affecting the production chain, as well as the single rate stabilization of the exchange rate by the government, the effect of short-term and emotional behavior of the exchange rate has not been considered. The related diagrams are presented in Figures 3, 4, and 5.

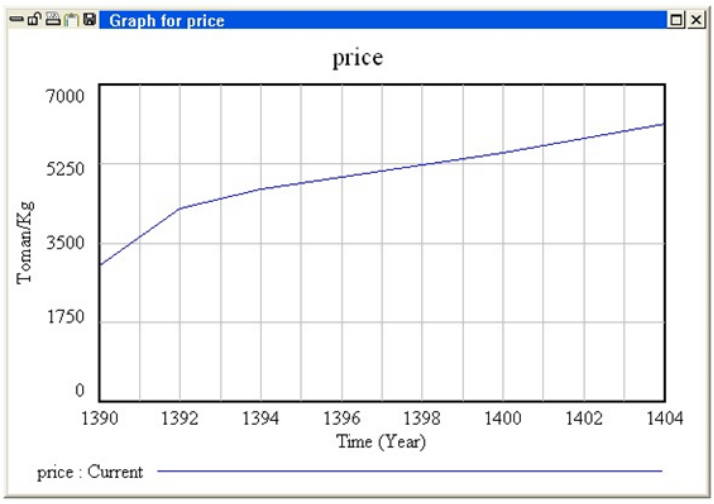

Figure 3. Price diagram.

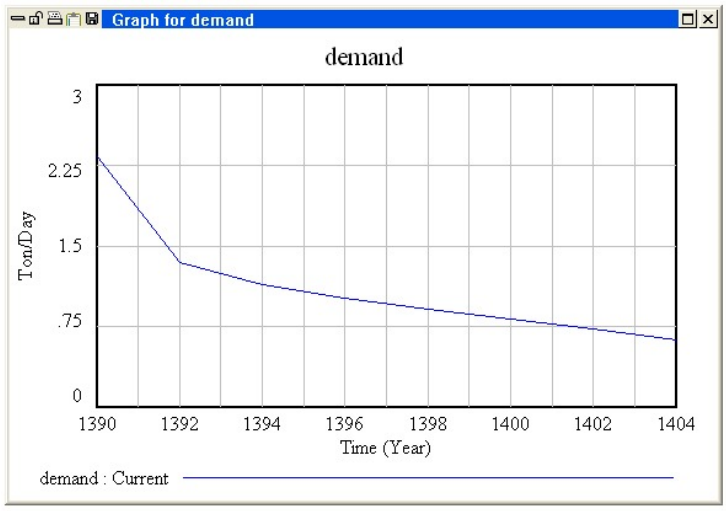

Figure 4. Demand diagram.

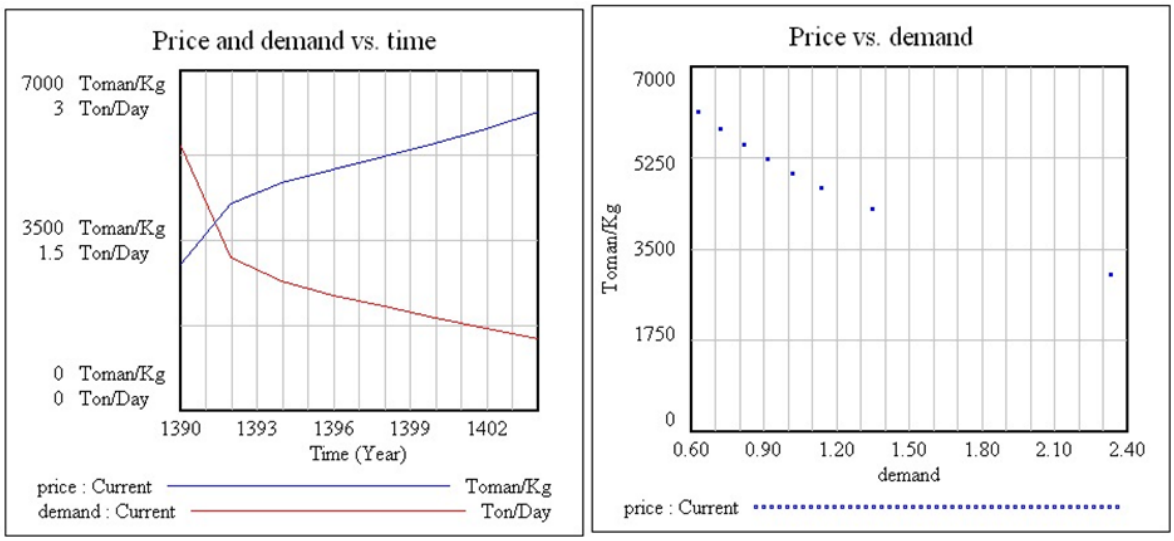

Figure 5. Comparison of the price and demand diagrams.

3.2.2. Analysing the behavior of the variable "production volume" in the model

In the simulated graph, the production volume of about 3000 tons per year is considered a long-term goal based on the company's capacity development plan, despite the decrease in domestic demand due to the increase in price and the profitability of exports. In addition, in construction, this volume exceeds the domestic consumption and is intended for export. It should be noted that the government is obliged to pay serious attention and support to manufacturing industries to maintain this growth trend until 1404. The planning period between 1390 and 1404 is considered due to the importance of the 1404 horizon in the country's development vision document. Figure 6 shows the production volume diagram.

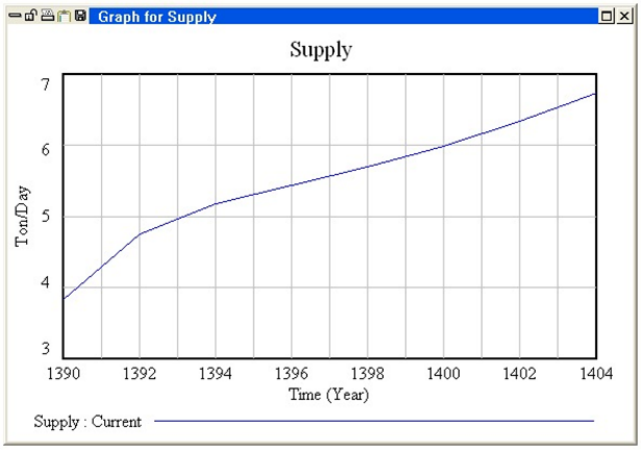

Figure 6. Diagram of production volume.

3.2.3. Analysing the behavior of income flow in the model

In the explanation of the income circulation chart, it should be mentioned that this amount of income from 1390 to 1404 was due to the development of other sectors of the metal industry, including rail protection and switchboards, as well as stability in the construction process. which requires the allocation of a suitable part of the development process in the construction industry, as shown in Figure 7.

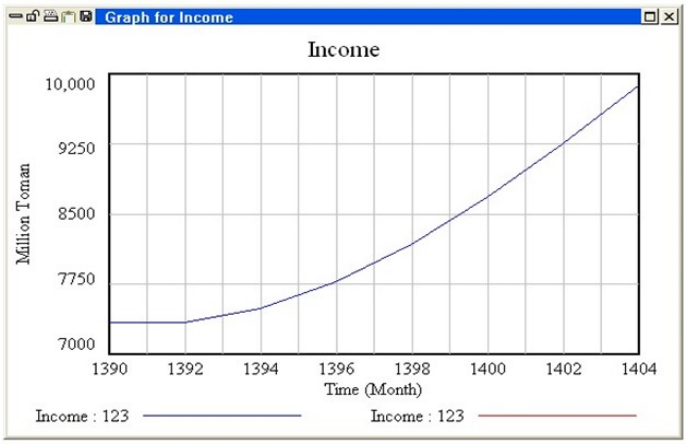

Figure 7. Diagram of income.

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3.2.4. Analysing the behavior of the variable "working capital" in the model

Although the working capital was smaller than the actualized income at the beginning of the simulation, the company's financial power is found to gradually increase in a desirable gradient, as observed in the diagram, with the improvement in the country's economic conditions and the possibility of acquiring loans in reasonable interest rates as well as improving and developing the product export and the return of part of the foreign currency income and its subsequent addition to the working capital. This diagram has been shown in Figure 8.

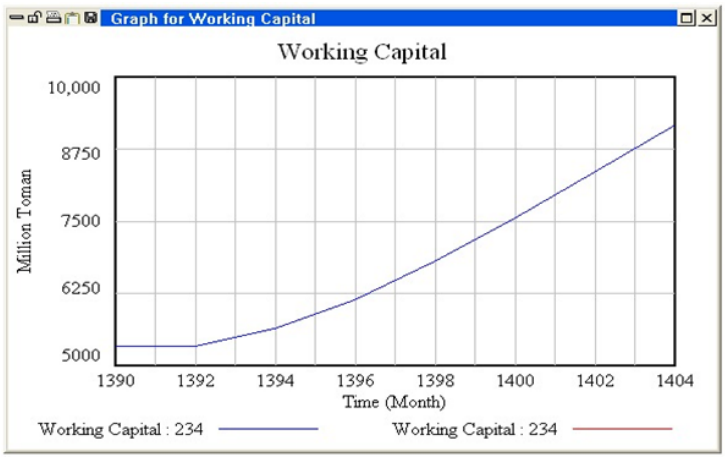

Figure 8. Diagram of the working capital.

3.2.5. Analysing the behavior of the variable "industrial units' development" in the model

In this diagram, the total growth and development of the metal industries sector of the province has been taken into account for the years from 1390 to 1404 based on an average 6-percent growth rate per year and export development, which means that about 340% of the growth can be witnessed in contrast to the base year in 1404. This diagram has been shown in Figure 9.

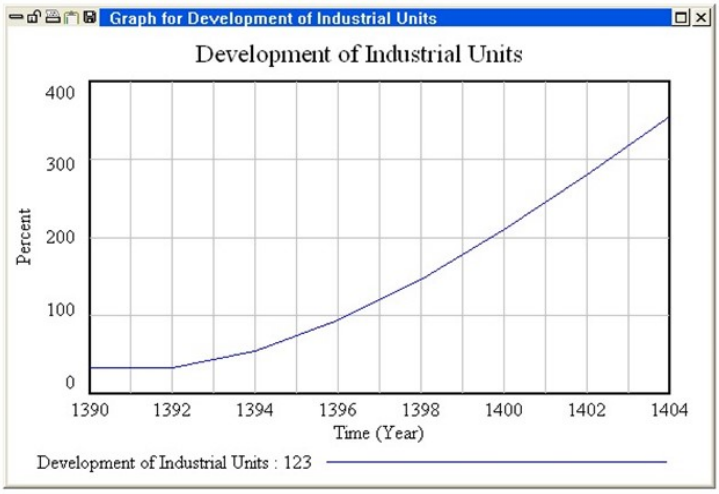

Figure 9. Diagram of the industrial units' development.

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3.2.6. Analysing the behavior of the variable "exports" in the model

At the beginning of the new presidential term, the export rate was set at 800 tons per year, and according to the government's policies in the agreement on the comprehensive program of joint action and improving the conditions for signing foreign contracts, it was about 1200 tons per year in 1396 (in all export products) Increased. This year, the sharp decrease in exports occurred due to the political tensions between Iran and the United States and the possibility of the United States withdrawing from the JCPOA and its final withdrawal. Of course, it is expected that with the correct and effective management of the foreign policy in 1397, based on the strategies devised by those in charge, the issue will be resolved, and the export rate will eventually reach 3000 tons per year. The 1404 horizon of this diagram is given in Figure 10.

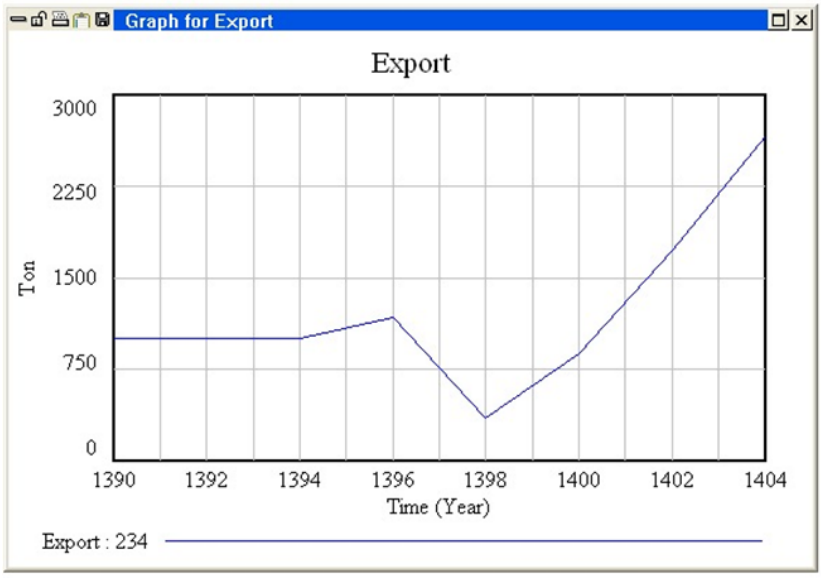

Figure 10. Diagram of export.

3.2.7. Analysing the behavior of the variable "the missed sale" in the model

This chart shows the behavior of lost sales in the model. Based on this, this production unit has faced an average annual loss of sales of 400 tons. This amount has slightly increased due to the specific time conditions of 1396 and 1397 and the JCPOA crisis. However, it is expected to decrease with the resumption of stability in the production market and the balance between demand and supply. However, due to many factors affecting the production market in Iran, it may never reach zero. The graph of lost sales is given in Figure 11.

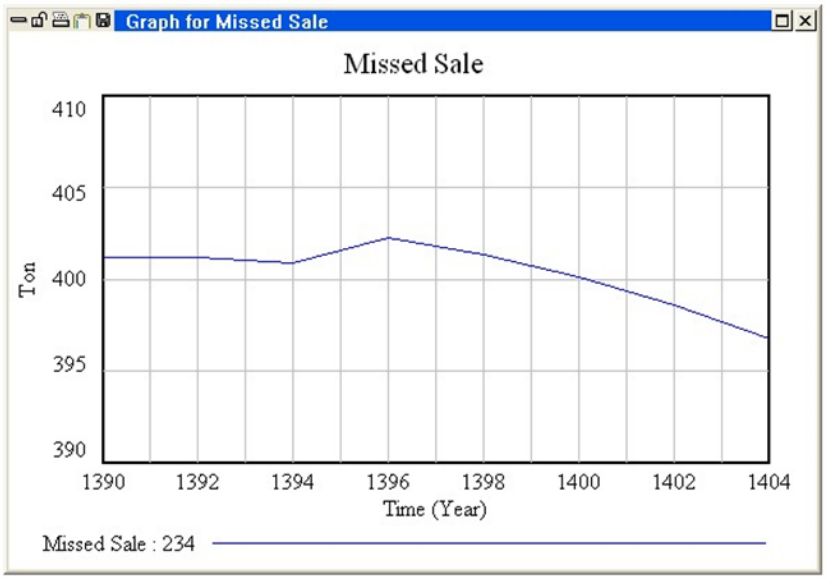

Figure 11. Diagram of the missed sale.

The diagrams for some of the other variables, like effective management or supportive policies, have not been presented herein for their lower importance and the high risk of calculation risk.

4. Conclusion

The existence of the missing loops has caused the province's metal industries to encounter numerous challenges in industrial and business activities. By identifying these loops, the province's metal industries can overcome their challenges, turn the threats into opportunities, and take maximum advantage of them. There is a significant difference between application and research in improving and assessing supply chain performance. It is expected that this research can bridge the gap by identifying the factors influencing the performance of the supply chain. Since resolving such issues based on the current mathematical and linear methods is confronted with many limitations, the present study tried to use a systematic approach for identifying and analysing the missing loops of the production chains in the metal industries of Kermanshah Province. One of the most significant ways to achieve this is by applying a strategy known as system dynamics. Evidently, the changes do not co-occur, and they undergo a dynamic process. Due to the same reason, the mutual interaction of various factors is needed for them to originate because it is not easy to comprehend and curb the dynamic phenomena, and this leads to an increase in their complexity; hence, the recognition of the correct direction for change would become very difficult. Therefore, one of the major challenges for the manufacturing units of the industries is recognizing the proper change and taking measures to

make it happen. The present study endeavored to identify and offer an appropriate analysis of a supply chain to recognize the missing loops influencing the chain's performance, thereby evaluating their interrelationships and effects on the entire system. The simulated model of the chain was designed using these variables based on the “system dynamics” technique using Vensim Software. According to the real nature of the studied industrial unit and the existence of sufficient information on the behavior of these variables in the unit above, the simulated behaviors were compared with reality. The results were tested based on the available methods. According to the high match between the simulated model’s performance and the real performance of the chain, it can be stated that the identified variables have predominantly been the same main and effective variables influencing the behavior of the chain performance. To improve the scales defined in the identification of the missing loops of the supply chain, the policies that are comprised of such suggestions as changing the amounts of some variables, changing some relations, eliminating some variables from the model, and/or adding several variables to the model were offered that finally led to the presentation of the several following policies:

(1) In this business, the revision and corroboration of marketing activities were investigated as the first scenario for reaching a higher market share and profitability. For now, the intended industrial unit does not see much of a marketing activity.

(2) The participation policies and bank supports that cause the availability of good loans with low-interest rates to the business units and provide them with sufficient cash supplies.

(3) Omission or reduction of the tax on added value for reducing the price of the product sale causes an increase in the income; the implementation of this policy would cause a reduction in the price of the product and enhance the units’ competitive power, and the business entity can receive a larger volume of the market demand to have its income finally increased and be provided with a more significant number of financial resources.

(4) The government’s sponsoring policies through consideration of the governmental subsidies, cash or non-cash, like giving a share in the production basket of the steel factories that would bring about a reduction in their referring to the intermediaries and finally reduction in the finished price of the products in such a way that a 5-percent reduction will be seen followed by a 50% increase in the demand.

(5) Activation and development of R&D units.

(6) Supporting exports within the format of creating relationships between the manufacturer and buyer, reducing the difference between the governmental and free currency rates and/or accurate currency rate payments, and guaranteeing the capital return in export.

(7) Revision and reviewing of the tax regulations and granting of tax exemptions to key and growing industries

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Disclosure statement

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

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