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Applying system dynamics approach to modelling effects of strategic production performance on supply chain: food and beverage industries

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Abstract

Food and beverage industries have decisive rule due to amount of employment and significant income generation. At micro perspective, due to the wide range of influencing factors, trends do not follow linear behavior and their analysis with non-dynamic tools is challenging. In general, the food and beverage industries in Iran, in addition to the global challenges, are facing many problems that make the prevailing environment more complicated. Among these problems, we can mention the old equipment, difficult access to quality raw materials due to sanctions and the instability of economic indicators. Therefore, if strategies performance cannot be adjusted in line with the market, the resulting losses can be significant and irreparable. In this paper, we developed a system dynamics model (simulation in Vensim) to investigating the production strategies and market in a complex space. For this purpose, we run the simulation 12 times with respect to 4 policies and 3 scenarios. The results show that due to profitability, the strategy of deleting loss products achieve the highest score of performance. Meanwhile, strategy of hybrid production (outsource and factory production) selected due to market penetration.

Keywords: Systems dynamics; food and beverage industries; quantitative simulation; stock and flow chart; vensim software.

Paper Type: Original Research

1. Introduction

The value of the food and beverage industry will reach from 3.5 billion dollars in 2022 to 3.7 billion dollars in 2023, which is equal to 5.7% annual growth. Although the war between Russia and Ukraine, and outbreak of the Corona pandemic, has caused an impact on this market, the value of this market will reach 4.6 trillion dollars by 2027 (World Market Report, 2023). The largest market share belongs to drinking products and this group will experience the highest market growth rate. Geographically, East Asian countries and developing countries are expected to experience the greatest growth. The market value of the Mena region in 2018 was equal to 145 billion dollars, which is 6% of the global share, and of this amount, the largest market share belongs to Turkey, Pakistan, Egypt, Saudi Arabia and Iran (Ali & Abul Mag, 2021). The food and beverage industry are considered one of the most important food industries in the world, which includes a chain from seed cultivation to the modern process

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of production, distribution and retail. According to Figure 1, the amount of income from the food industry globally has an upward trend on average and, it is predicted that this trend will continue.

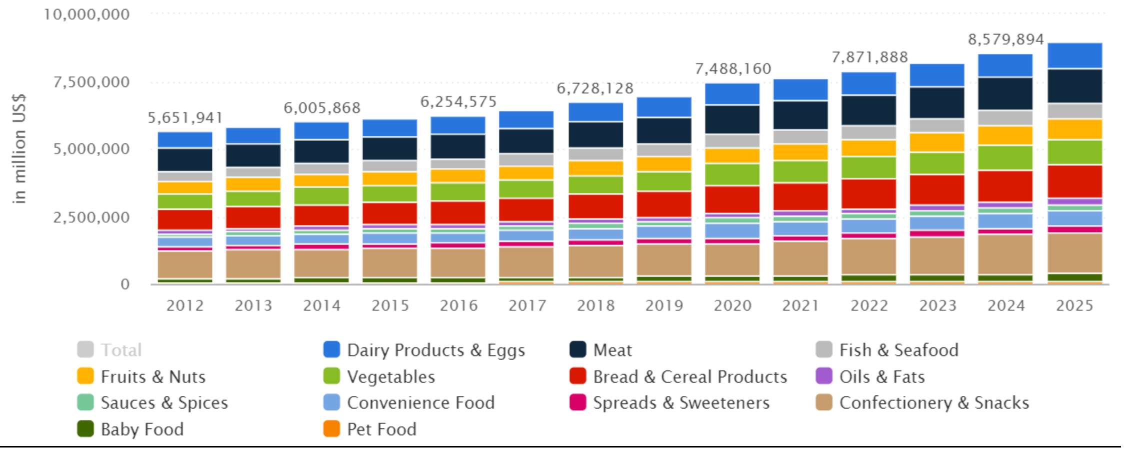

Figure 1. The growth trend of food industry income in the world by different areas (World Food Organization report, 2020)

This is despite the fact that according to Figure 2, if we look at each of the food groups, the percentage of income growth (especially with the spread of the Corona pandemic), has undergone non-linear changes and will challenge linear predictions in the coming years. For example, the prepared products group experienced a significant increase and then a decrease due to the pandemic. At the same time, the group of vegetable products and sweets were also accompanied by a decrease in income.

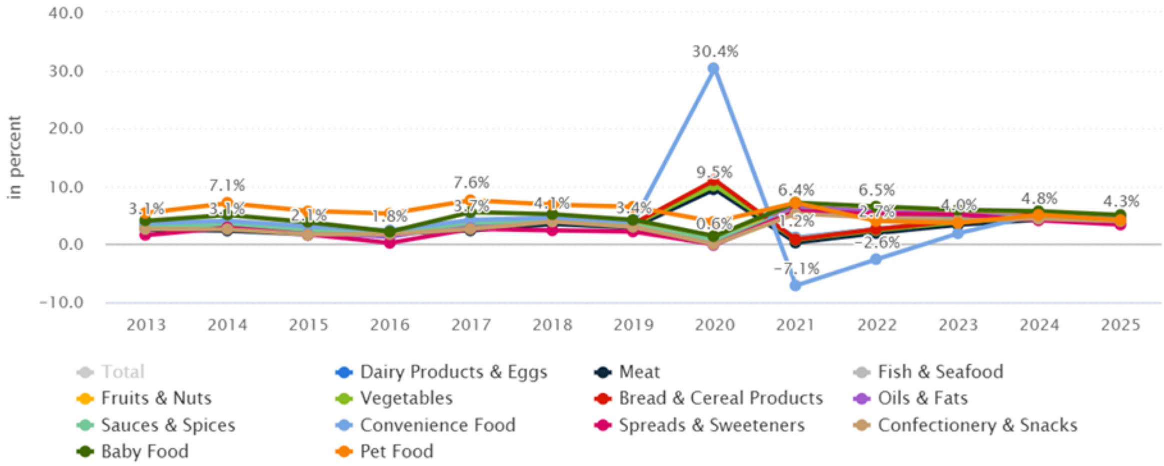

Figure 1. Growth percentage of food product revenues (World Food Organization report, 2020)

The atmosphere of uncertainty has affected not only the income but also the methods of distribution. For example, during research in 2020, more than 80% of the orders for these products were ordered online in America, which shows the rapid changes and uncertainty in distribution patterns. Before the corona pandemic, online orders were around 55% (Morcillo-Bellido, 2019). This is despite the fact that such a jump is not observed at the global level. (World Food Organization report, 2020). Examining performance statistics and figures at micro perspective shows much more fluctuations than at the macro or global level of indicators. If organizational strategies are not responsive to future conditions, they will sometimes lead to the elimination of the organization and bankruptcy (Jeon et al., 2020).In Iran, the consumption of food and beverage products has been shrinking over the past four years, and the consumption of selected product groups of each household has decreased from 145 kg in 2015 to 126 kg in 2018. Among the selected product groups, the total volume of consumption has decreased from 2147 thousand tons in 2015 with 8.2% decrease to 1971 thousand tons in 2018. In the period of 2015-2018, the consumption of sweets and beverages decreased by 20% and 23%, respectively, while the consumption of canned food and ready-made food increased by 21% (Report on the latest developments of the food industry of Iran, 1400).In general, the food and beverage industries in Iran, in addition to the global challenges, are facing many problems that make the prevailing environment more complicated (report on the nature of the food industry in Iran, 2018). Among these problems, we can mention the old equipment, difficult access to quality raw materials due to sanctions and the instability of economic indicators (Amiri et al., 2020). One of the important issues in the field of strategy is to align production strategies with market strategies. For example, it can be mentioned to align the development of production capacities with market development strategies. On the other hand, with very high changes in demand in different seasons, as well as unexpected entry into new markets or the sudden elimination of competitors, it is possible to use the capacity of fee-based production to meet demand (Hecht et al., 2020). Also, on the other hand, the discussion of resilience and survival of companies is important. As a result, it is necessary for the supply chain of these types of companies to be flexible and put the customer at the center of their planning. Therefore, the development of strategic plans of companies in the long term should be based on agile production planning and at the same time focus on cost reduction all over the supply chain (Jonsson & Rudberg, 2014). For example, the mass producers, which are known for their productivity, were challenged rapidly in demand and competitors. They faced heavy bank debts because they could not respond quickly based on market changes (Hugos, 2007). Motorola's market share increased from 60% in 1994 to 31% in 1998 and by 2002. Due to the inability to adapt to the rapid development of technology and demand, this share reached less than 16% (Finkelstein, 2004). In order to implementing wrong strategies, this company also fired employees of research and development departments to reduce its costs, which caused it to lose more of its market share (Harrigan, 2012). Based on this, a topic called responsive supply chain has been raised, which is about the flexibility of the entire chain in the face of market changes. In 2004, Lee stated that strategies based on cost reduction and productivity increase are quite vulnerable in the face of unpredictable changes in demand and may lead the organization to bankruptcy (Lee, 2002). Also, Porter stated that focusing on strategies to reduce costs and increase productivity, the company's performance is involved in short-term planning with extensive changes instead of long-term planning, and as a result, there may be no desire to invest in the production of new products (Porter, 1996).In the context of the use of dynamic solutions, at first, the investigation of market dynamics using classical models is used, which is known as the spider web model (Ricci, 1930) (Mackey, 1989). In this model, its providers believed that the demand is a function of the price and the supply process is a function of the price delay. These two basic hypotheses lead to the price equation, which includes the initial price, supply elasticity, and demand elasticity. Not taking into account the flow structure and accumulation of the market, the weakness in describing temporal changes in the multifaceted state in industries are among the weaknesses of this method. Although the inherent concept of this model is still useful and used in describing events and research. Production fluctuations have also been studied by dynamic system analysis. For example, we can refer to different models of supply and demand in different industries considering multiple products.In one of the classic dynamic system models, Meadows (2002) presented a model of commodity price cycles. The results of this model show that a small change in the input variable leads to significant fluctuations in the output. In other hand, Sterman presented a general model of supply and demand using the dynamic system methodology. In his model, he mentioned loop (Sterman, 2000). Based on Chakravarti's point of view (Chakravarti, 1989), when different units are effective in the company and each one can find a separate approach alone, the production strategy will fail. As a result, careful planning of strategy should be considered through a top-down approach (McKiernan & Morris, 1994). Hence, many production strategies have failed. Identifying problems, anticipating problems and developing system models in the process of creating a production strategy defines five separate approaches for strategy formulation, which are: Autocratic, approaches, transformational, rational, learning and political approaches (Babuto, 2016).To sum up, it can be explained that today, due to the change in the environmental conditions of markets, such as the occurrence of natural hazards, pandemic events, economic fluctuations and international relations, we are facing the phenomenon of uncertainty in the markets (Chen and Voigt, 2020). When there is uncertainty, the application of strategies may not have an effect based on initial expectations and sometimes the results are obtained in the opposite direction of the goals. In such a situation, the use of traditional strategic planning approaches, in the face of disturbances and uncertainties, does not have the necessary flexibility and cannot be the basis of planning (Abu Bakr and Mohammad, 2019). Therefore, it is necessary to evaluate the prevailing uncertainty environment in the review of strategic functions, using dynamic analysis (Vandenbrink, 2020). Based on this, the main question of the current research is how the strategic performance of production affects the market share and profitability of companies?

2. Literature review

Golrizgeshti et al. conducted research under the title of evaluating the dynamics of the supply chain in the presence of product elimination in 2023, in which the development and elimination the product portfolio. Emphasizing on product elimination strategies, the effectiveness of its implementation on the efficiency of different parts of the supply chain has been investigated (Golrizgashti et al., 2023). This study, which was conducted using the dynamic system methodology, in addition to the conceptual explanation, has quantitative modeling and simulation.

In another article, Ghafarzadegan and Tajrish (2010) investigated the management of the transitional economy in the consumer goods market. This article, which uses the dynamic system approach, examines the cement industry as a case study. The model used in this research consists of two parts: supply and demand. In formulating different sections of stakeholders based on their role, it is shown how the changes in cement price can affect them and also how the stakeholders influence the price is also formulated.In another research, Rebs and Brandenburg (2019), investigated sustainable supply chain management using the dynamic system method. In this research, authors with content analysis tool, do a review of the previous literature in the field of supply chain management. The areas that are emphasized in the literature review are economic (expenses and GDP), environmental area (energy, materials and necessities, water and land) and social area (population, salaries and wages, public health and Education) In another article, Hettesheimer (2017) investigated the effects of production strategy on the production cost of a lithium battery unit. A production strategy includes four sub-strategies that examine the location of a production system, how to increase capacities and, the portfolio of products produced, and the depth of vertical integration. The methodology used in this article is the dynamics of systems, which has been examined based on two scenarios that consider the use of different technologies for battery production and, calculate the effect of their use on the total cost of the unit (Hettesheimer, 2017). In another study, Prusty et al investigated the shrimp industry using the dynamic system approach. Using Porter's five forces, the authors first counted the strategies and then prioritized them using the Delphi technique. In the following, the strategies calculated by dynamic system modeling. These strategies include production strategy, environmental strategy, marketing strategy and a set of financial strategies. Based on the modeling done, each of these strategies was investigated alone (Prusty, 2011). In this research, production strategies are analyzed according to the feedback of market dynamics, and this issue has not been investigated in the previous literature, and all the studies are focused only on the inside of the supply chain variable. Also, no analysis has been done on the food and beverage industries in the previous literature.

3. Methodology

This research is an applied type and the case study is food and beverage industry. The researched society is considered to be the managers and specialists of companies producing food and beverage products. For modeling, we used really financial and marketing data. The research process is shown in Figure 3. As it can be seen, in the first step, analysis of available statistics, the study of the current state of the trends, at micro and macro dimensions has been done. In the following, based on the searches made in the previous studies, the dimensions of the problem and the relevant areas were investigated, meanwhile, the challenges and appropriate solutions were investigated. With the help of experts' opinions, we conducted semi-structured interviews to define problems and hypothesis. Considering that in order to formulate the structure, (stock-flow diagram) has been used. For this purpose, we used Vensim software and different scenarios and policy studied.
The result's Reliability and Validity checked by reproducing the behavior. In the behavior reproduction method, by using the available historical data, the past behavior of each variable is investigated and if it can produce a behavior with the reality in the pastime periods, it can be concluded that the prediction results of the next periods are reliable, and its validation will be accepted (Sterman, 2000).

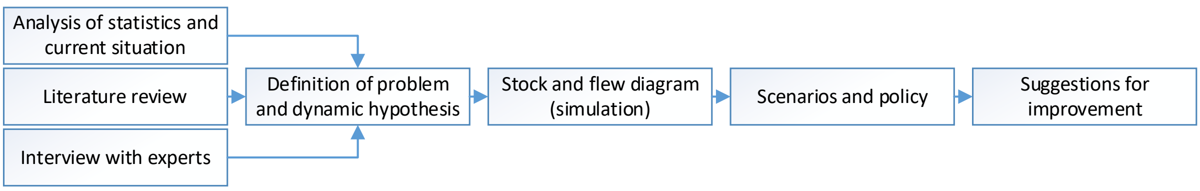

Figure 3. Research Process

4. System dynamic simulation

The first step is the definition of dynamic hypothesis, such as follows (sterman, 2000):

• Uncertainty affects the effectiveness of production strategies.

• Product line strategies has an effect on product market share.

• The implementation of strategies to delete the unprofitable products has an effect on increasing the market share of the products.

• The strategy of updating and modernization in the production sector affects the market share of the products.

• The use of production capacity in the long term has a two-way relationship with the share of the product market.

As mentioned earlier, quantitative modeling has been done using Vensim software. Results reported in monthly time step (84 months) from 2020 to 2027.

The products that were simulated separately are: herbal spirits and syrups, jelly, lemon juice, coffee, sauce and vinegar. Also, the considered markets are as follows:

• Chain stores: In this section, the product market in medium and large chain stores is considered. Stores with an area of more than 200 meters and more than 5 branches are classified in this subsystem.

Retailes: A retail distributor serves as an intermediary between the manufacturer and the consumer, providing a distribution channel for the manufacturer to indirectly sell their products. The distributor also takes care of procuring inventory from the manufacturer and fulfilling the orders to their customers.

Internet Markets: This section includes all websites and internet applications that sell virtually. In this section, only online stores that have warehouses were considered.

4.1. Markets simulation

Figure 4 shows the market segment modeling. The calculation of the market volume is modeled dynamically. For this purpose, the LOOKUP function is used. Based on this, equation 1 shows the method of calculating. After calculating the net rate of market volume, based on the amount of net rate growth, the demand accumulation variable is calculated through equation 2, and finally, by calculating the total market volume, using equation 3, the amount of the monthly definite order for each product It is calculated.

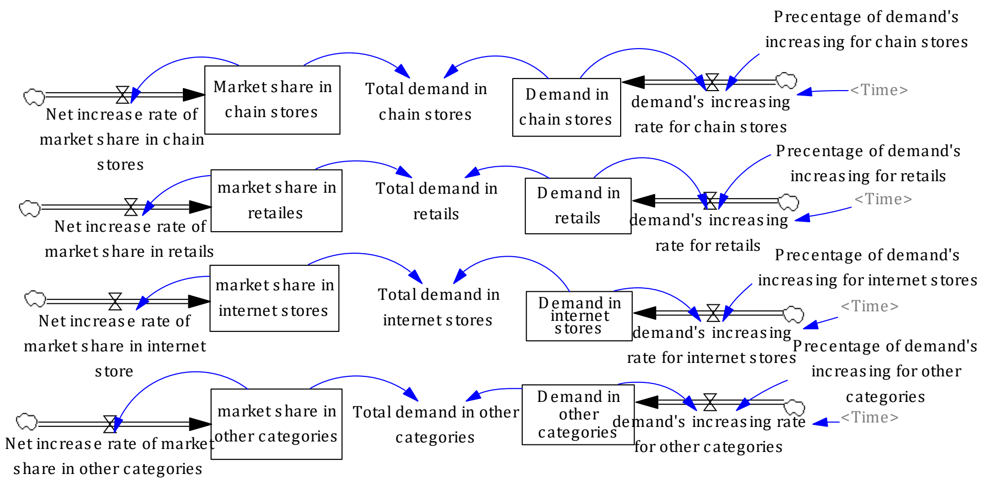

Figure 2. Stock-and- flow diagram of market simulation

$$DIR = Lookup(PDIR, time) \quad (1)$$

$$\mathrm{DI} = \int_{t_0}^{t_n} (\mathrm{DIR}(\, \mathrm{dt} \quad (2)$$

$$TD = DI \times MS \quad (3)$$

4.2. Sale simulation

Figure 5 shows the simulation structure of the sales. The main feed of this section is the amount of production. The production is divided into two parts: payed and factory. In the first step, the number of orders to each of the distribution channels is calculated, which is described in equation 4. Service level obtain from demand and delivery. This variable is calculated through equation 5, and in order to calculate the net rate of increase in the product market share, we used Lookup function has been used (equation 6). Obviously, if the service level is lower than a certain level, it will lead to a negative rate and reduce the market share of the products.

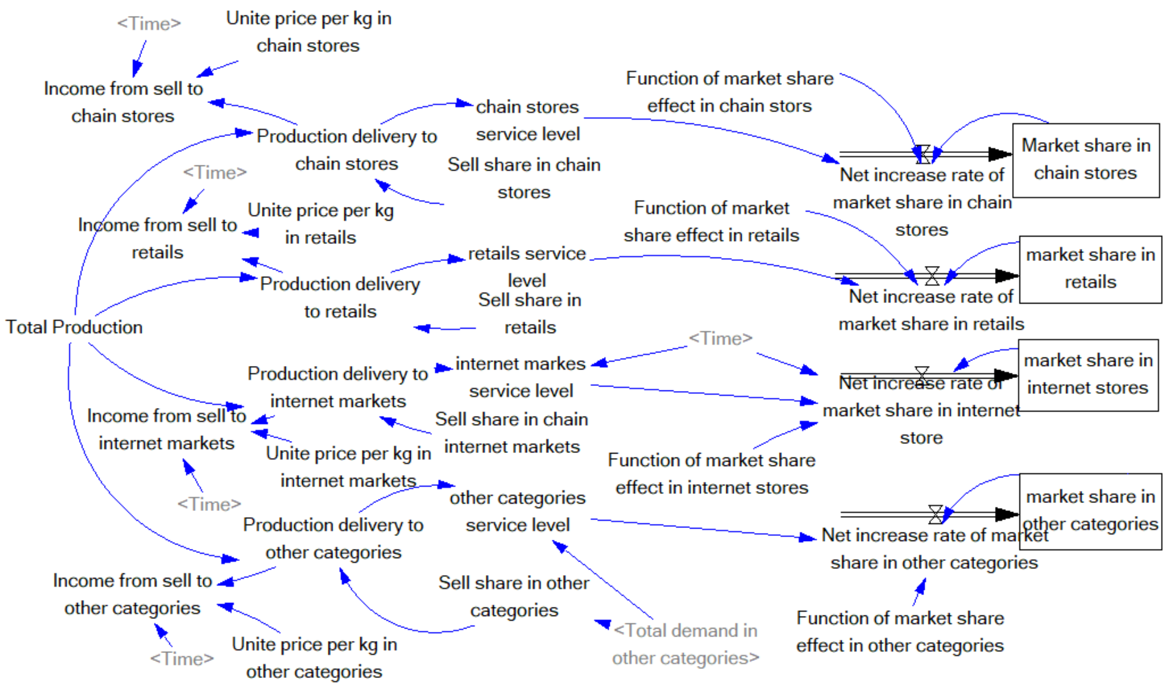

Figure 3. Stock-and- flow diagram of sale simulation

$$PD = TD \times SS \tag{4}$$
$$PD = TD \times SS \tag{5}$$
$$NIM = Lookup(SS, FMS) \tag{6}$$

4.3. Production Simulation

This section related to the adjustment of the factory and outsource production capacity. According to the previously mentioned literature, the amount of development investment is based on demand. First, the unit cost of development equivalent to the production of one kilogram of product is calculated. In this way, based on the economic inflation rate, there will be a percentage increase. This percentage is entered into the calculations using the Lookup function externally. After that, the rate of increase in the production capacity is calculated as equation 8. It should be noted that increasing the capacity requires many activities and is entered into the system with a delay, in this research the delay of capacity development is considered to be 18 months.

$$DIN = Lookup(DINR, time) \tag{7}$$
$$FPCD = DELAY1I\ (DI/UCD, 0,18) \tag{8}$$

Based on the factory capacity, the outsource production capacity is adjusted accordingly. Development delay considered 6 months. Also, when 80% of the factory capacity is completed, the capacity development operation will take place.

Factory production will be considered next 10 month and before that, production will be done only by the outsource production. The amount of factory production is calculated by equation 9.

$$FPD = if\ then\ else(TD > FP, FP, TD) \tag{9}$$

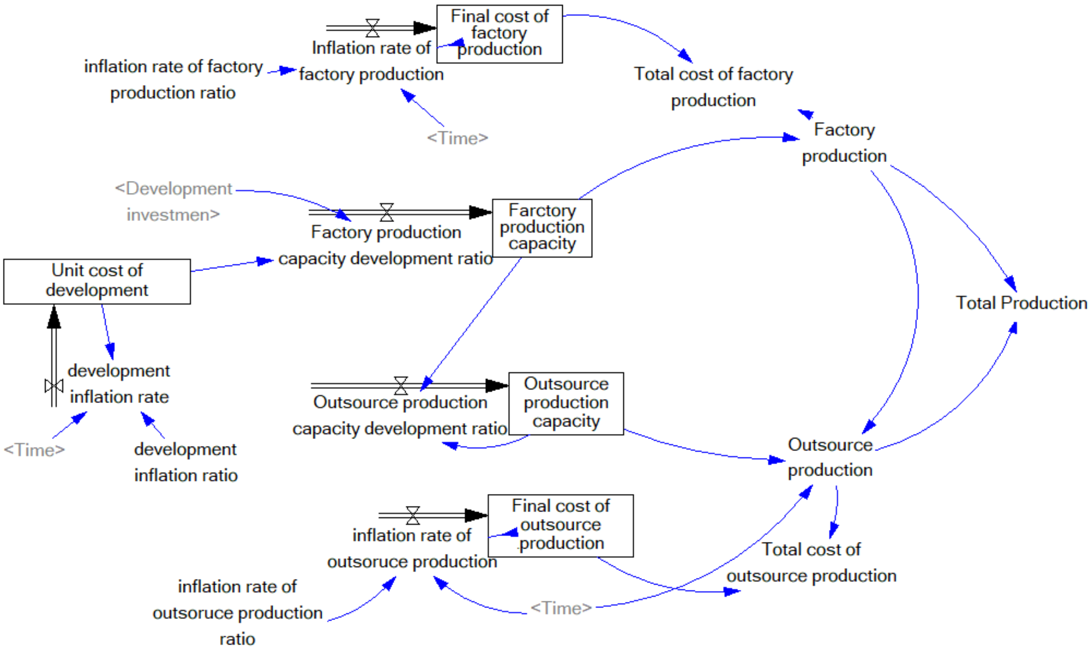

Figure 4. Stock-and- flow diagram of Production simulation

4.4. Financial simulation

The profitability is one of the simulation reference charts, which is Income minus expenses. The considered elements are as follows (as shown in fig 7):

- General costs of distribution and sales: including all rent, bills, administrative costs, etc., regardless of the fixed production volume.
- Sales revenue: includes all revenue from product sales
- Capacity development investment: includes loans taken for the purpose of capacity development.
- Production costs: all production costs according to the volume of production.
- Development investment: includes payment and cost of loan received for capacity development.
- Loan repayment: after the breathing period, the repayment of the loan taken in this transaction.
- Overhead costs: include all production overhead costs.

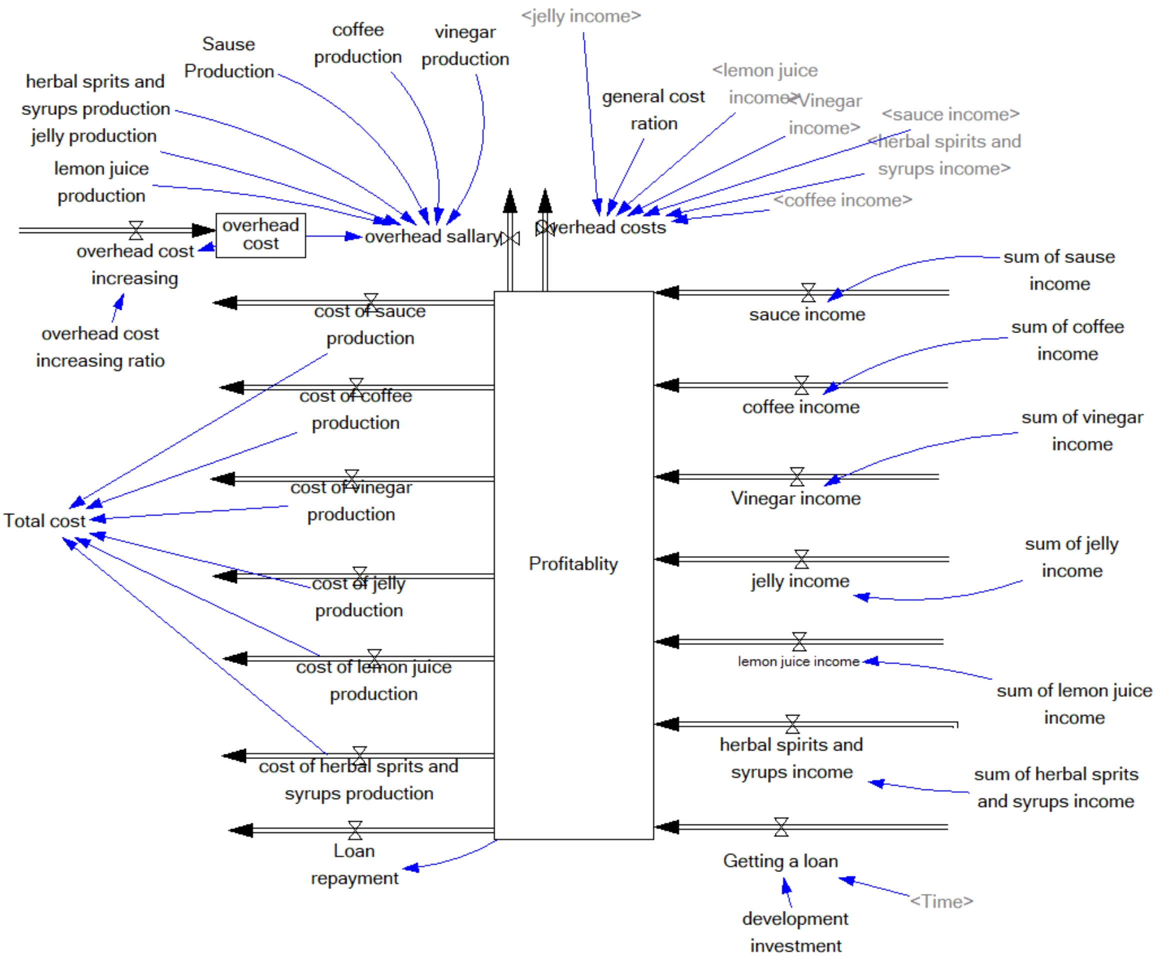

Figure 5. Stock-and- flow diagram financial simulation

The notation for variables used in stock and flow diagrams are summarized in table 1.

Table 1. Stock and flow diagram notations

Row	Notation	Description	Unit
1	DIR	Demand's increasing rate	Million Toman/month
2	PDIR	Percentage of demand's increasing	Percentage
3	DI	Demand in any category	Million Toman
4	MS	Market share	Million Toman
5	TD	Total demand	Million Toman
6	PD	Production delivery	Kilogram
7	TD	Total Production	Kilogram
8	SS	Sale share	Percentage
9	NIM	Net increase rate of market share	Percentage
10	SL	Service level	Percentage
11	FMS	Function of market share effect	Percentage
12	PCD	Production capacity development ratio	Kilogram/month
13	DIN	Development inflation rate	Rials/month
14	DINR	development inflation ratio	DML
15	FPCD	Factory production capacity development ratio	Kilogram/month
16	DI	Development investment	Rials/month
17	UCD	Unit cost of development	Rials/Kilogram
18	FPD	Factory production capacity	Kilogram/month
19	FP	Factory production	Kilogram/month

5. Numerical results

In the first step, the validation of the model was done. By using the behavior reproduction method, the two variables of total income and total production cost in the base run were compared with historical data (Streman, 2000). Figure 7 shows this comparison. As can be seen, the output of the model matches the historical data with good accuracy.

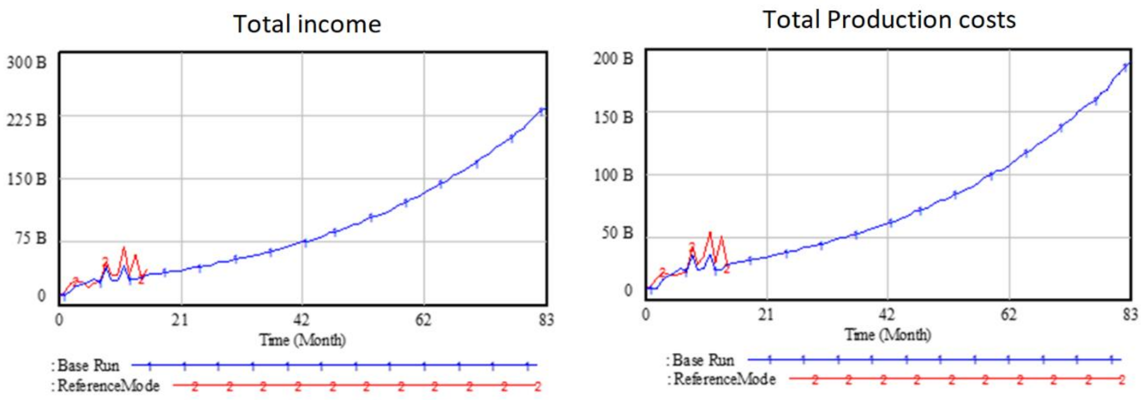

Figure 6. Validation results of the model with behavior reproduction method

In order to simulate and analyze the problem, a combination of scenario and policy has been used. The scenarios are considered as an external factor that is not calculated inside the model and only its effects are entered into the model exogenously. Policy is the strategy of improvement and it is defined and implemented according to different scenarios and finally the best policy that achieves the most improvement in most scenarios is selected. The defined scenarios are as follows:

• Scenario 1, economic inflation stagnation: it is assumed that after two years (24-time units) the slope of fixed and variable production costs will increase.

• Scenario 2, the reduction of customer's purchasing power: it is assumed that the market of non-essential and luxury products will shrink in 2 years due to economic problems and the corona pandemic.

• Scenario 3, continuation of the status quo: it is assumed that the current trend is maintained

The considered policies will be as follows:

• Policy 1, only paid production: in this policy, it is assumed that fee production will be used in all production capacity.

• Policy 2, Maximum use of factory production capacity: in this policy, it is assumed that the share of paid production will reach zero within 9 months.

• Policy 3, combined use of factory and commission production capacity: in this policy, it is assumed that the fee-based capacity will be used until the end of the production demand overflow simulation time.

• Policy 4, deleting unprofitable products, two groups of harmful products, including spirits, syrups, and lemon juice delete from portfolio

Result of combining policies and scenarios, it forms a 3x4 matrix. The coding of each scenario simulated in the software is described in the following table:

Table 2. Coding of the policies and scenarios in simulation

	Scenario 1: Inflationary stagnation	Scenario 2: the reduction of customers' purchasing power	Scenario 3: Status quo
Policy 1: Only paid production	S1-P1	S2-P1	S3-P1
Policy 2: Maximum use of factory production capacity	S1-P2	S2-P2	S3-P2
Policy 3: Combined use of factory and commission production capacity	S1-P3	S2-P3	S3-P3
Policy 4: deleting unprofitable products	S1-P4	S2-P4	S3-P4

average market share and profit charts has been considered as a reference charts. Figures 8 and 9 show the results of combining 3 scenarios and 4 policies.

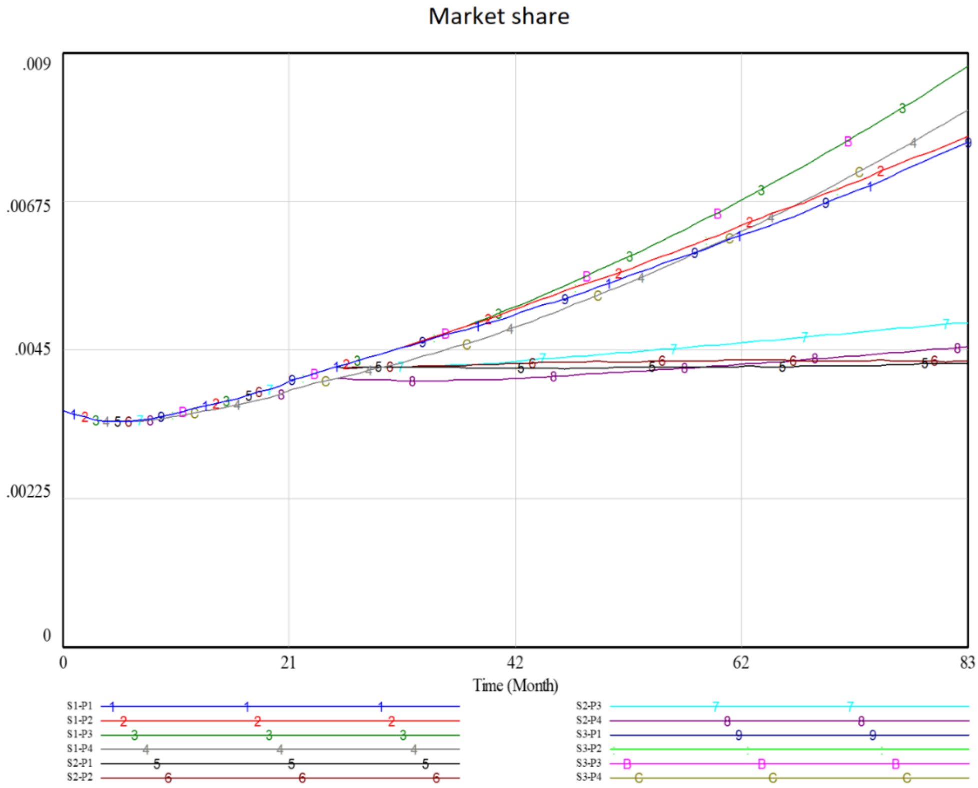

Figure 7. Model simulation results: Market share (percentage/month)

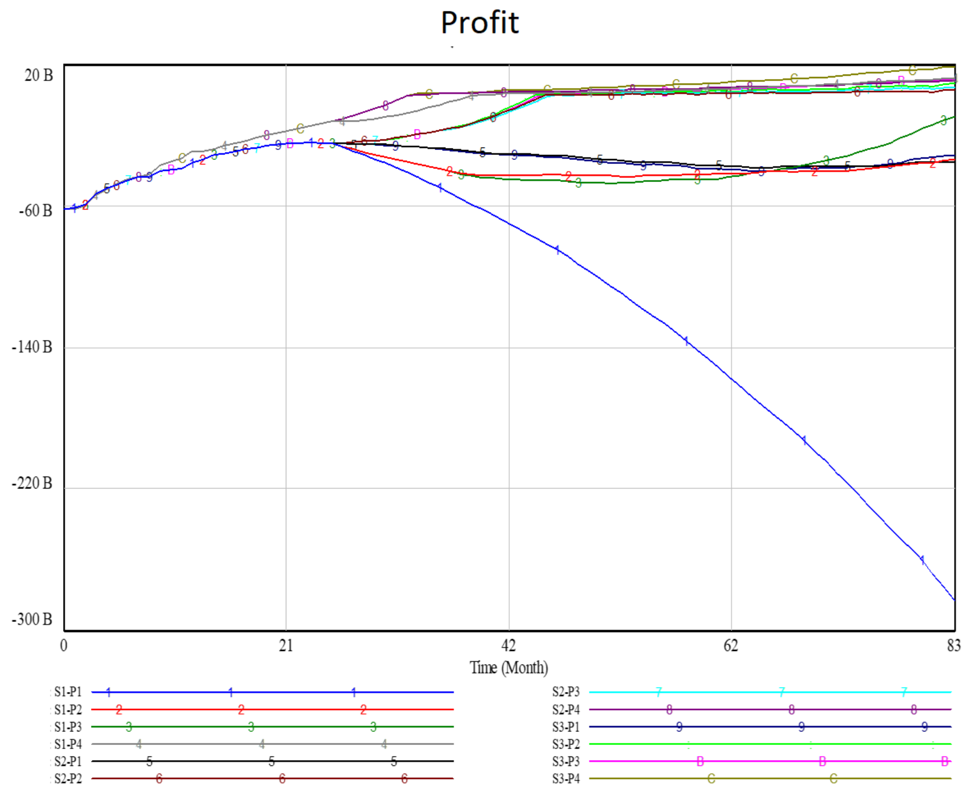

Figure 8. Model simulation results: Profit (Rial/month)

In order for measuring the effectiveness of each scenario we used Likert scale to rank those (Joshi et al., 2015). The level under the graph during the simulated time period is considered and ranked each policy between 3 and 9. Considering that, the scores of each policy in the two subjects of market penetration strategy and profitability strategy are presented in Table 3.
If the company's strategy is based on increasing the profitability, the policy of deleting unprofitable products will be the most profitable in the 3 scenarios under consideration. But if the company's strategy is based on market penetration and gaining more shares than competitors, the combined production strategy (maximum factory production along with fee overflow production) will achieve the highest service level and market penetration as a result.

Table 3. The rank of each policy in the simulation results

ROW	Policies	Points with a profitable approach	Points with market penetration approach
1	P1	9	11
2	P2	15	17
3	P3	21	17
4	P4	27	27

6. Discussion and conclusion

Production companies are always faced with many challenges and errors in the conditions of market uncertainty, which sometimes, it can lead to the collapse and bankruptcy. However, many brands and products have appeared and declined. Today, due to the very rapid changes in the markets, the occurrence of unforeseen events, the agility and flexibility of organizations has decisive rules, which if these two issues don't have accuracy, it can even lead to losses.
In the meantime, the issue of determining the strategy is very important and plays a key role. Among the strategies of manufacturing companies, there are production and marketing strategies that can affect the agility and flexibility. Production strategies have made significant progress in recent years due to the competitiveness of the markets, and each strategy has its own advantages and disadvantages.
As a result, a reliable platform that can simulate the effectiveness of implementing strategies virtually can be of great help to the decisions of company managers. System dynamic models are one of the best modeling tools in the uncertainty space. These models, by considering the effective dynamics in each subsystem, can simulate the outputs of each scenario with decent accuracy.
The main goal of this research is to create a reliable platform with acceptable validity and reliability in order to examine the strategic performance of production. It can be used to measure the effectiveness of the implementation of production policies and the best policy according to market conditions (Wei and Zain Gang, 2022).
In the review of the previous literature, it was found that, no research has been done considering the dynamic feedback of the market due to the implementation of production strategies in food and beverage industries. Among the production strategies, development of production capacity, deleting of products, outsourcing and factory production were considered. Each of these strategies were quantified in the form of different simulation scenarios so that the effectiveness of their implementation can be measured. Based on this, 3 scenarios and 4 policies were defined and simulations were performed 12 times.
The results show that each production strategy has different effectiveness and performance compared to the environmental conditions and the type of attitude and strategic goals. For this reason, it is necessary to study each strategy in environmental conditions in order to be able to choose the most effective ones. For this purpose, two reference charts (profit and market share) were defined in this research. The simulation output shows that if the company's strategic goals are focused on profitability, the strategy of removing unprofitable products can bring more profit during the simulation period. Unprofitable products are generally products whose life cycle is in decline and while spending resources for production, they are not productive (Zhu & Shah, 2018).The deleting of this products reduces the wastage of resources and makes it possible to invest in development sectors and increase productivity and ultimately lead to an increase in profitability.
If the main goals include penetrating the market and improving the position of products in the markets, the combined production strategy (outsourcing and factory production) creates the highest service level and lead to more market share.
The results of this study can be used by company managers so that they can consider production strategies in sync with market feedback. Also, the platform of the model created in this research can be a suitable infrastructure for defining and checking the effectiveness of other production strategies.
Therefore, on this basis, it is suggested that after formulating the production strategies based on the company's goals, before implementing each strategy, the effects of its implementation should be analyzed using simulation based on the structure presented in this research. Deleting the product is suggested as one of the effective strategies in reduce losses and increasing profitability, which can significantly reduce costs and increase profitability. Also, development of production capacity (combination of outsource and factory production) under the condition of

performing dynamic market and demand simulation can be a suitable solution to increase market penetration and increase profitability in the long term.

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