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In the Name of God, the Compassionate, the Merciful

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Modeling New Product Diffusion in a Competitive Market Using Agent-Based Simulation

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A B S T R A C T

The prediction of the results of introducing a new product into the market is one of the vital issues facing the organization's executives before investing in marketing activities. The impact of various factors on the market, as well as the specific characteristics of the market, depending on the region and its product type, has made it difficult to predict market behavior. In Iran, retailers are effective players, especially in the FMCG market. This paper aims to suggest a model for the marketing managers to predict the result of their new product lunch to market considering their special market attributes. Agent-based modeling, as a tool for modeling complicated systems, can be helpful for simulating real-world conditions. In the present paper, agent-based modeling is used to model the market, including retailers and consumers with particular profit functions, and two producers compete with each to maximize their profit. The introduction of a new soft drink in the Iranian market over three years is considered as a case study. The results of policy implementation were evaluated using the decision support system developed in this study. The user interface of this system has been developed with Matlab software, and its model core with SQL Server. The results show that paying attention to the needs of retailers and consumers simultaneously, and changing policies based on long-term profitability, create success in the new product diffusion process. The analysis of a competitive environment, the role of retailers in the market, and the repeat purchase behavior of consumers are instructive. These can provide valuable points for marketing managers to customize the model to their special market and product.

Keywords

Agent-based modeling, New product diffusion, Competitive market, Retailers, Repeat purchase

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1. Introduction

Innovations have become an indispensable factor for securing the long-term success of enterprises (Tseng, 2008). However, multiple factors often affect the success of the innovation diffusion process, which entails high costs for organizations, such that the failure of the diffusion process may sometimes terminate an organization's life. Therefore, it may be vital to anticipate the results of the diffusion of innovation for organizations before introducing their new products to the market.

Innovation diffusion is the process by which an innovation is communicated over time among the participants in a social system (Rogers, 1962). Diffusion models as a tool for predicting the results of innovation diffusion have been largely based on the model suggested by (Bass, 1969). These are usually cumulative models with a macro-level approach to systems, and their development is based on differential equations. These models try to provide simple and overall approximations of systems in the future. Even though these models do not take into the account the heterogeneity of consumers and details of their decision rules and interactions, the biggest problem of these models is that the Bass model requires two of the most important events as inputs that managers would like to predict (Chandrasekaran and Tellis, 2017).

In recent years, simultaneous changes in agent-based modeling and the ability to process large volumes of data make it possible to focus on the details of and diversity in social networks. In agent-based modeling based on a bottom-up approach, the interactions between components and the impact of these interactions on the overall system behavior can also be modeled. Agent-based diffusion models in marketing have mainly been developed since 2000 and provide an appropriate basis for managers to make more accurate decisions. In most practical studies, the basic assumption is that innovations are available to consumers as soon as the diffusion process begins, and the role of intermediary agents such as distributors and retailers in the product diffusion network is considered less. Also, less attention is paid to the competitive environment and the impact of changes on continuing consumer behavior after the primary acceptance of innovations.

The present paper attempts to (i) investigate a competitive environment with two brand owners (producers) and their mutual reactions based on market changes within a game theory structure, (ii) consider the important role of retailers as intermediary players in the market, with rational and profit-seeking decision rules, (iii) and also considers repeat purchase behavior of consumers who continue comparing products before each purchase even when they have previously accepted and used theme.

Continuing the research on new product diffusion process modeling based on agent-based modeling, the present study focuses on fast-moving consumer goods (FMCG), especially on carbonated drinks in the market of Tehran as a retailer-based and price-sensitive market in FMCG goods.

The rest of the paper is organized as follows: Section 2 reviews the existing literature and the research gaps. Section 3 describes the case study. The structure and components of the model and the procedures and parameters of the simulation process are described in section 4. In section 5, we examine the reliability and validity of the model, and in Section 6, the policies are introduced, and the results of the implementation of policies are shown. Finally, the conclusion and recommendations for future research are discussed in section 7.

2. Literature review

The term "diffusion" embraces concepts such as contagion, mimicry, social learning, and organized dissemination Strang and Soule (1998). Diffusion research is an interdisciplinary field rooted in anthropology, sociology, geography, political science, economics, and marketing Kiesling et al. (2012). Ryan and Gross (1943) were the originators of the diffusion paradigm. They found that social contacts, social interaction, and interpersonal communication had an important influence on adopting new behaviors Valente and Rogers (1995). Early efforts to mathematically model the spread of a new product in a marketplace were rooted in analogies from models of epidemics, biology, and ecology (Mahajan and Muller, 1979).

Along these lines, Fourt and Woodlock (1960) developed a simple penetration model to forecast sales of new grocery products. Other studies proposed similar models, but the most influential contribution to date was made by Bass (1969). He specified that an individual's probability of adopting a new product depends linearly on two forces: One that is not related to previous adopters and is represented by the parameter of external influence (traditionally denoted as p, e.g., advertising and mass media); and one that is related to the number of previous adopters, the parameter of internal influence (denoted as q, e.g., word of mouth - WOM) (Goldenberg et al., 2000). Since then, many studies have been done based on the Bass model. Meade and Islam (2006) reviewed the wealth of these studies from a forecasting perspective and concluded that, despite the efforts of many authors, few research questions had been fully resolved. They emphasized that research should include forecasting new product diffusion with little or no data and focus on forecasting future behavior instead of estimating the future using past behavior. In the last two decades, many efforts have been made to eliminate the constraints on aggregate models based on the Boss model. Agent-based models, which differ fundamentally from both aggregate differential equations and aggregate simulation approaches such as system dynamics (Milling, 1996), are believed to overcome the problem because of their individual-based modeling approach.

The bottom-up modeling approach can easily incorporate micro-level diversity in adoption, bounded rationality, imperfect information, and individual heterogeneity regarding attributes, behavior, and linkages in social networks (Kiesling et al., 2012).

Agent-based modeling analyzes and implements simple rules of interaction between members. The possibility of combining the effects of these interactions at the macro level enables analysts to model the complexities of social realities, including interactions in the new product diffusion process.

The literature on agent-based models of innovation diffusion is divided into two major streams: theoretical insights and practical applications.

In the field of theoretical findings, research has mainly been carried out in three areas (Kiesling et al., 2012): the impact of consumer heterogeneity on innovation diffusion (Alkemade and Castaldi, 2005; Goldenberg et al., 2000; Delre et al., 2010), the role of social influence in diffusion processes (Delre et al., 2007; Bohlmann et al., 2010; Xiao and Han, 2016) and the effect of promotional marketing strategies on diffusion processes (Delre et al., 2007; Moldovan and Goldenberg, 2004; Goldenberg and Efroni, 2001).

In the field of practical applications, many studies have been done since 2000 that have had a strong influence on the operational use of agent-based models by managers and decision-makers in marketing: In primary studies, such as Berger (2001), the impact of various policies on simulated models with one product is investigated in a non-competitive environment. In subsequent years, attention gradually moved toward the impact of competitive environments in the agent-based models have been seen in (Günther et al., 2011; Kim et al., 2011; Fazeli and Jadbabaie, 2012). Fazeli and Jadbabaie (2012) proposed a game-theoretic analysis of a strategic model of competitive contagion and product adoption in social networks. Of course, in this model, the main players are consumers, not innovation owners, who are, in fact, the main policymakers and competitors in the market.

Paying attention to a subject neglected in research, repeat purchases in competitive environments in (Stummer et al., 2015) simulating the Diffusion of Competing Multi-generation Technologies in Günther and Stummer (2018) and multi-channel choice behavior in Sonderegger-Wakolbinger and Stummer (2015), as the latest effort to fill the gaps in the literature are considered. Of course, the above studies have not addressed the game theory to enter the competition in the model as an effective idea in this area.

The major players in the market, apart from producers and consumers, are retailers. These players have been noticed in a few studies, such as (Heppenstal et al., 2006; Kaufmann et al., 2009; Sturley et al., 2018). Of course, in their proposed models, retailers as agents have no decision-making power or heterogeneity, and they only have a role in determining retail prices. This is despite the fact that retailers are the main factors in the market, and while they compete to attract more consumers, they also have a significant role in determining the availability of products and innovation diffusion. Therefore, they must be entered into diffusion process modeling as important and independent agents. In the past, and by Jones and Ritz (1991), which was a development of the Bass model and did not use agent-based modeling tools, the role of retailers was also considered. That research considered the role of retailers as a precondition (intermediary) of consumers' access to new products.

A review of the literature and existing research gaps show the need to develop a model that considers a competitive environment with active producers as the main policymakers in the market, independent retailers with special profit functions as active agents, and repeat purchase analysis after initial acceptance and the impact of distribution costs in the profit function as important issues in reality. In addition, effective and dynamic reactions to market changes after competitors' entrance of new products show the need for competition approaches to diffusion process modeling. In the present paper, the players are producers who compete in a market in a game theory structure. Also, retailers and repeat purchases and the impact of distribution cost are considered.

Table 1: Practical studies on launching a new product using ABM

Author	Agent-based modeling	Competitive environment	Independent retailers effect	Repeat purchase analysis	FMCG
Berger (2001)	✓	▯	▯	▯	✓
Kaufmann et al. (2009)	✓	▯	▯	▯	✓
Zhang et al. (2011)	✓	▯	▯	▯	▯
Kim et al. (2011)	✓	▯	▯	▯	▯
Xiao and Han (2016)	✓	▯	▯	▯	▯
Heppenstall et al. (2006)	✓	✓	▯	✓	▯
Günther et al. (2011)	✓	✓	▯	✓	▯
Fazeli and Jadbabaie (2012)	✓	✓	▯	✓	▯
Stummer et al. (2015)	✓	✓		✓	▯
Rosales et al. (2018)	✓	▯	✓	✓	▯
Stummer et al. (2021)	✓	▯	✓	✓	▯

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Table 1 lists practical studies on launching a new product using ABM and shows the main topics covered in this article.

3. Case study

This model utilizes the case study of fast-moving consumer goods (FMCG), specifically carbonated drinks. One of the FMGC products was selected for use in the proposed model for the following reasons: the extreme role of retailers in the distribution of these products; the short repurchase period of the products; high rates of the infidelity of consumers to the brands of these products; the possibility of studying competitive policies; and the availability of actual data to evaluate the validity and reliability of the model.

According to statistics from the Majles (Iranian Parliament) Research Center, Iranians imbibe 33 liters per capita of carbonated drinks. Based on an average of 3.5 people per family, that means consumption equal to 1 small can or bottle per day for each family and generalizing the average of the country to Tehran and considering that one producer manages the major shares of the carbonated drink market in Tehran, the consumption parameter of the model is set. From now on, the major brand will be called the old brand, and its producer, as the marketing policy maker, is called the old producer. The new product that starts competing with the main brand when the diffusion process is run is called the new brand, and its producer, as the new producer, makes related marketing policies in the model.

The practical data on new product distribution is extracted from an existing database of archived transactions of a distribution company in Iran for 3 years from the beginning of a carbonated drink lunch period. This information shows the number of purchases made by retailers of the new and old brands, as well as changes in three-year pricing. More details about the case and agents' behavior are described in the next section.

Results of our field research in Tehran shows that in the case of carbonated drink, when the quality of products are similar, price plays a major role in affecting consumer behavior, and the power of loyalty in our field research is 0.34. The power of brand loyalty (POL) is calculated as the ratio between the price of the new brand and the price of the old brand that the consumer chooses the new brand if the ratio is equal or less. Results of field research also show that when the ratio is between POL and 1, the probability of a new brand selection can be calculated from the linear probability distribution function described in formula 2.

4. The proposed model

Based on Rand and Rust (2011), there are seven decisions to be made when designing a model using the ABM approach: Scope of the model, Agents, Properties of the agents, Behaviors, Environment, Input, and output of the model are mentioned throw describing the model in figure 1.

In the proposed model, consumers are agents embedded in a social network communicating with each other and purchasing from their neighbor retailers. Retailers are agents having communicated to their neighbor retailers with the ability to make decisions to purchase from producers and determine retailer price based on their benefits function.

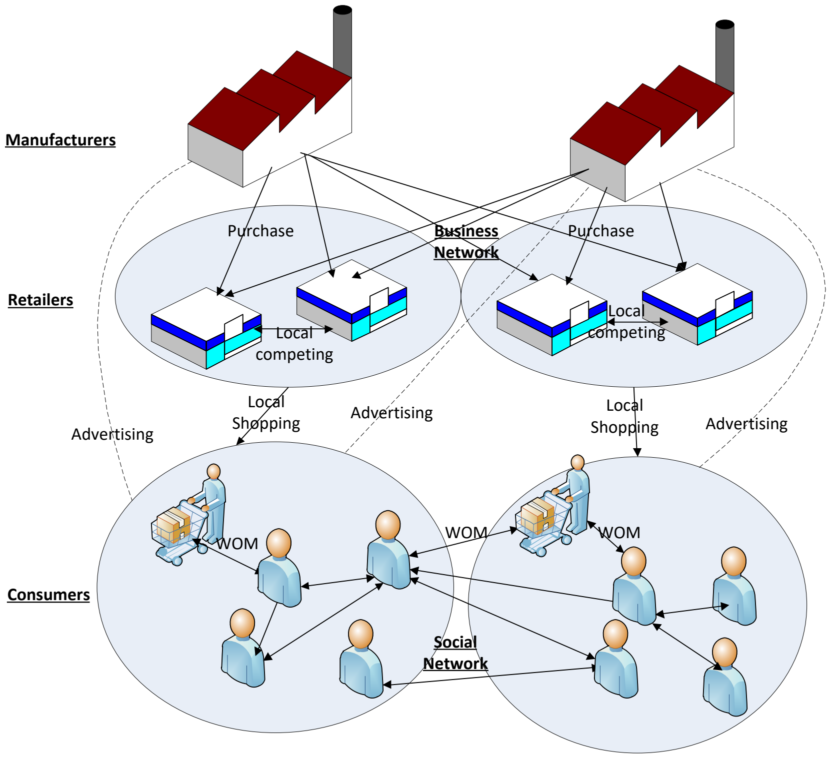

Figure 1: Model Framework

The diffusion process begins with the arrival of a new product to the market while consumers are purchasing the main brand from retailers and retailers from producers. Consumers accept the new product under the influence of external variables (advertising) and internal variables (word of mouth) at a specified rate. Consumers may change retailers because they overcharge compared with their neighboring retailers and also decide which brand to buy based on formula 2.

Retailers also periodically determine product prices based on their previous profit and the lowest prices of neighboring retailers in the market. In this process, they try to simultaneously increase their profit and consumers. During the implementation of the model, producers also attempt to change the wholesale price to increase their profits according to information obtained from their profit changes in the past periods and based on specific rules in the game theory structure. In the following sections, the agents, network structure, diffusion process, pricing process, purchasing process, and policies of producers will be described.

4.1. Agents

- Products: In the proposed model, the products are fast-moving consumer goods (FMCG), specifically carbonated drinks.
- Consumers: Households in 22 districts of Tehran whose population is determined based on the 2011 census and based on population and income levels are different.
- Retailers: Business owners who purchase goods from producers or distributors and sell them to end consumers. In Iran, in the case of FMCGs and in terms of the magnitude and diversity of goods, these can be grouped into five types. These retailers also have independent businesses, and their product selection criteria are profit margin, the volume of sales, and the distribution network Miremadi and Faghani (2012). Based on population and income levels in each area, the number and types of retailers are different; these differences are applied in the model. Each type of retailer agent has a different attraction coefficient for probable consumer attraction.
- Producers: They are the brand owners and main policymakers in the model. They apply their policies and change marketing factors, especially wholesale prices in this model, to increase market share and profitability. It is assumed that a producer exists first, and all consumers have been purchasing the product from it. At the start of the diffusion process, a new product enters the market and takes a part of the market share of the primary product, so the main producer is forced to react.

4.2. Network

The social network is in operation for a period of 10,000 days, equivalent to almost 27 years, before the diffusion process begins, based on the model described by Albert and Barabási (2000).

A common property of many large networks is that the vertex connectivity follows a scale-free power-law distribution. This feature is a consequence of the two generic mechanisms that networks expand continuously by adding new vertices and reconnecting vertices in preferred network construction. A model based on these two ingredients reproduces the observed stationary scale-free distributions (Barabási et al., 1999). The network of consumer relationships in our model is constructed by a preferred and gradual approach, consistent with the principles of making pseudo-realistic models.

With the completion of the consumer-consumer network, the construction of the consumer-retailer is created in this way: Consumers in each area are connected to retailers from the same area based on the determined possibility of attracting consumers for each retail type.

Later, when the diffusion process is run, each retailer who is one of the three available retailers for any consumer is periodically evaluated. If there is a better retail price, the retailer may be replaced. This algorithm creates a network in which the right to choose the best retailer is given to the consumer and simultaneously leads retailers to compete to attract more customers.

Now, assuming that the entire network is shaped and all the consumers are buying the main brand, the diffusion process of the new brand in the network can begin.

4.2.1. Diffusion and acceptance process

- The probability of acceptance by each consumer *(i)* in period *(t)* is calculated as follows: (Amini et al., 2012).

$$p(i,t) = 1 - (1-p)\prod_j (1-q_j) \quad (1)$$

- In the above formula, p is the probability for consumer (*i)* that is influenced by external advertisement, and q is the probability of consumer (*i)* that is influenced by word of mouth of accepted consumers *(j)*. These values are entered into the proposed model based on the amounts specified in Sultan et al. (1990): p=0.03, q=0.4. Later, verification tests on results show that the implementation of the model with these parameter values is robust, and they are matched to the real data.
- In the process of acceptance, only individuals who consume the product can have an impact on other individuals. So, not only should they first accept the new product, but also, based on the model described by Jones and Ritz (1991), the product should exist in one of their retail centers, and they should buy the product from the retailer at least once.

4.2.2. Consumer buying process from the retailer

As mentioned, the retailers a consumer selects are determined in each period of the model so that the consumer can go to one of the retailers in the consumer's home region in each period. Assuming that the consumer knows there is a new brand of product (the adoption process is complete), the price of the new brand is lower than the main brand, and the new brand is available in stores, the new brand is selected by the consumer by the following probability formula called brand selection probabilistic function in the present paper:

P (New Brand Selection) = (Old rp- New rp)/(Old rp – POL)
Where Old rp >= New rp (2)
Else P (New Brand Selection) = 0

P (Old Brand Selection) = 1- P (New Brand Selection) (3)

Where "Old rp" and "New rp" are the retailer prices of the main brand and new brand, respectively, and "POL" is consumer power of loyalty to the main brand.

4.2.3. Retailer pricing process

- The producers can only determine wholesale prices, which are the sale prices of the products to the retailers by the producers. Wholesale prices are determined based on policies set by producers.
- Each retailer in the model determines the retail price in this paper, and it is based on an algorithm referred to in (Heppenstal et al., 2006) as the Pricing Algorithm:
  - If the profit is rising, continue implementing the last price change;
  - If the profit is falling, increase the price.
  - If this does not work, decrease the price.
  - If the profit is constant (within a defined tolerance), keep the price constant.

The retailers periodically implement the above requirements, and appropriate decisions are made. The retailers also periodically check other retailers' prices and set the price close to the lowest region price based on a defined algorithm in the model.

4.2.4. Retailer buying process from producers

Each producer's sales agent visits the assigned retailers to sell his products in a specific period. The retailers determine the share of each brand on their shelves based on the income derived from each brand. This income is affected by the (i) consumer purchases and (ii) the retailer's profit margin. When producers' sales agents come, retailers order the amount of product based on the share of space for each brand, excluding the brand inventory on the shelf.

4.2.5. Producers' policies

It is assumed that each producer can change the value of marketing parameters such as the wholesale price, the proposed retail price, the amount and coverage area of advertising, the product distribution areas, and the visiting period to retailers to increase market share and profits. To simplify policymaking, only the prices are changed in different policies; other parameters are set at constant values. In the first step of policymaking, the initial wholesale and retail prices are set, and the results are checked. It should be noted that retailers change the retail prices of both brands during the model implementation; the values set at the beginning of model implementation are only the initial values suggested by the producers and have no control over retail price changes. Also, none of the producers can change the values of the model parameters during the model implementation. Later, in a competitive environment and according to information the producers receive from their situation in the market, each producer changes its wholesale price intending to increase its profit during the model implementation. The rule for determining the wholesale price is based on the algorithm used by the retailers.

5. Model test

A large number of independent and effective agents, complex and local interactions between agents, the impact of time in simulation results, and the dynamics in the system are some properties of our problem. Rand and Rust (2011) explain that the exhibition of these properties in the problem confirms that ABM is an appropriate solution for the problem and one of very few approaches that works.

5.1. Verification

Two experts compared the code with the model plan and verified the validity of the proposed model. In addition, corner case, sampled case, specific scenario, and relative value testing were carried out; the results confirmed the model's validity.

5.2. Validation

Validation is the process of determining how well the implemented model corresponds to reality. Four steps were taken to ensure rigor in validation:

1. Micro-face validation: Experts in the field of FMCG approved the utilization of the Pricing Algorithm introduced by Heppenstall et al. (2006) when a producer and a retailer faced a change in profit and sales. The retailers' behavior in the purchasing process, Consumer buying process from retailers, and Retailer pricing process were also approved.
2. Macro-face validation: the behavior of factors such as purchase and sale levels, wholesale price and retailer price, and also market share of the brands were evaluated. The difference between estimated factors and their real values was compared using the Theil-Sen method, and the cumulative behavior pattern of the model was confirmed.
3. Empirical input validation: The accuracy of input data such as population, price, and costs and their adaptation to the real data were confirmed.
4. Empirical output validation: Total sales were evaluated as one of the main outputs where input data were adapted to the corresponding real data.
5. Cross-model validation: It was performed by comparing our results both to the modified bass model formulated by Jones and Ritz (1991) and the basic bass model.

Four parameters of the model as input and correlation between results and the basic bass model and also real data as outputs are presented in table 2.

Table 2: correlation between results and conceptual model and real data

p_{BA} Probability of adding new vertices in preferred network construction	q_{BA} Probability of reconnecting vertices in preferred network construction	P probability of external effect in the acceptance process	Q probability of internal effect in the acceptance process	correlation between model acceptance rate and the Bass model (R2)	correlation between retailers' purchase ln model result and related real data (R2)
0.8	0.1	0.03	0.37	0.988	0.854
0.7	0.1	0.03	0.37	0.983	0.741
0.4	0.1	0.03	0.37	0.99	0.325
0.8	0.15	0.03	0.37	0.971	0.540
0.8	0.1	0.01	0.37	0.989	0.582
0.8	0.1	0.05	0.37	0.989	0.658
0.8	0.1	0.03	0.30	0.971	0.301
0.8	0.1	0.03	0.45	0.987	0.455

6. Model implementation

After verification and validation of the model, its parameters were set based on four policies, and the model was run. In these policies, the wholesale price and retail price of the main brand were fixed, and the prices for the new brand in each policy were set differently. Parameter values and results were as follows:

6.1. Fixed parameter values in pricing policies

- Model implementation period: equal to 1,000 days
- Impact of advertising: p=0.03
- Effect of WOM: q=0.4
- Period of change in the retail price: 45 days
- Period of retailer change by customer: 15 days
- Sales visits period for the main product and new product: 15-day period with a delay of 3 days
- Period and type of advertising: television advertising for the new product for 30 days from the beginning of the model implementation
- Advertising cost per day: 300 million rials
- Product distribution to the retailer: distribution in all regions and to all retailers is done from the beginning of the simulation for both products
- Distribution cost for each customer: 50,000 rials
- Loyalty power of main product: set at 0.34.

Table 3 shows the names of the policies and the values of the variables in policy development.

Table3: Policy values

Policy number	Policy name	New brand			Main brand		
		Cost price	Wholesale price	Retail price	Cost price	Wholesale price	Retail price
1	Balance price	4	6.5	8	4	8.5	10
2	Regardless of retailers' profit	4	7.5	8	4	8.5	10
3	Attention to consumers	4	6.5	7	4	8.5	10
4	Decrease profit and attention to retailers	4	5.5	8	4	8.5	10

NOTE: Values shown in thousands of Rial

Figures 2 to 5 present the cumulative monthly (30-day period) simulation results for each policy by displaying profit and sales for each product.

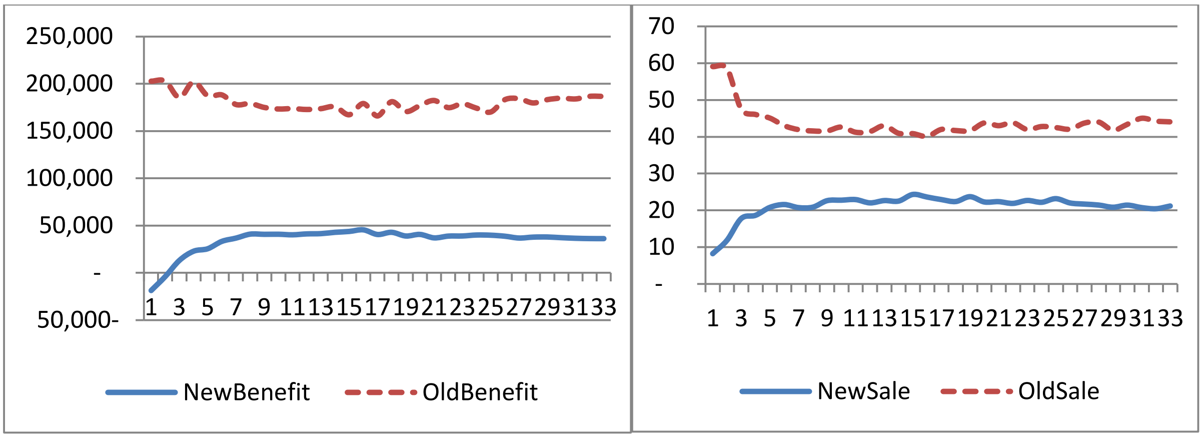

Figure2: Profit and sales for policy 1 (balance price)
NOTE: Profit: millions of Rial; sales: millions of cans.

The balanced policy considers both the retailers' profit and consumers' sensitivity to price. The simulation results show that the new brand achieves suitable and constant profit in the long term.

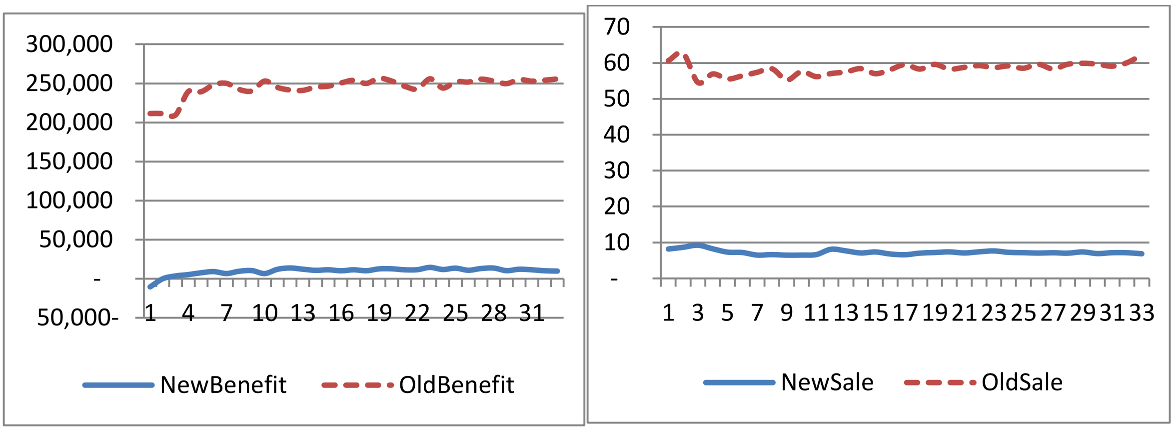

Figure 3: Profit and sales for policy 2 (regardless of the retailer's profit)
NOTE: Profit: millions of Rials; sales: millions of cans.

This is an expediency policy under which the new producer tries to allocate part of the retailers' profit to itself. In this case, retailers avoid allocating adequate space to the product themselves until the retail price increases enough to achieve optimum profit because of a high wholesale price and low profit for the retailers. As a result, although the new producer uses advertising to provide enough information to consumers to increase the population of adopters and assign the right retail price for consumers, lack of access to the new brand for consumers leads the new producer to don't achieve a high market share and appropriate profit.

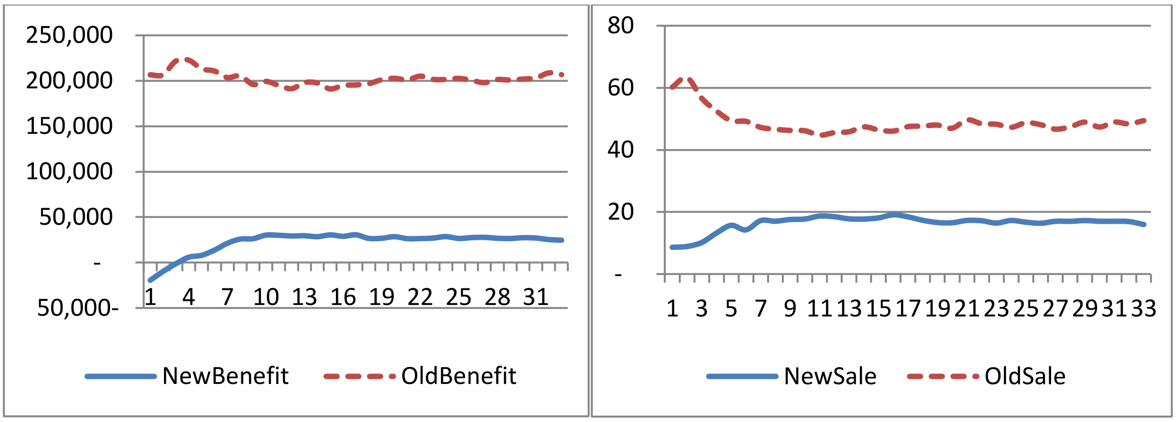

Figure 4: Profit and sales for policy 3 (attention to consumers)
NOTE: Profit: millions of Rials; sales: millions of cans.

This is a policy of high interest to consumers, in which the primary retail price set by the producer is decreased to attract consumers' attention. But it can be seen that retailers gradually increase the retail price because of their low profit and the possibility of retail price increment. In fact, retailer price reduction has a negative effect on retailers' profit and their purchase amount in the initial steps of the diffusion process, which leads to a lack of enough inventory of the new brand on retailer shelves. In other words, despite enough investment in advertising by the producer, there is no product to be bought by adopters, and the total profit of the new producer is lower in policy 3 compared to policy 1.

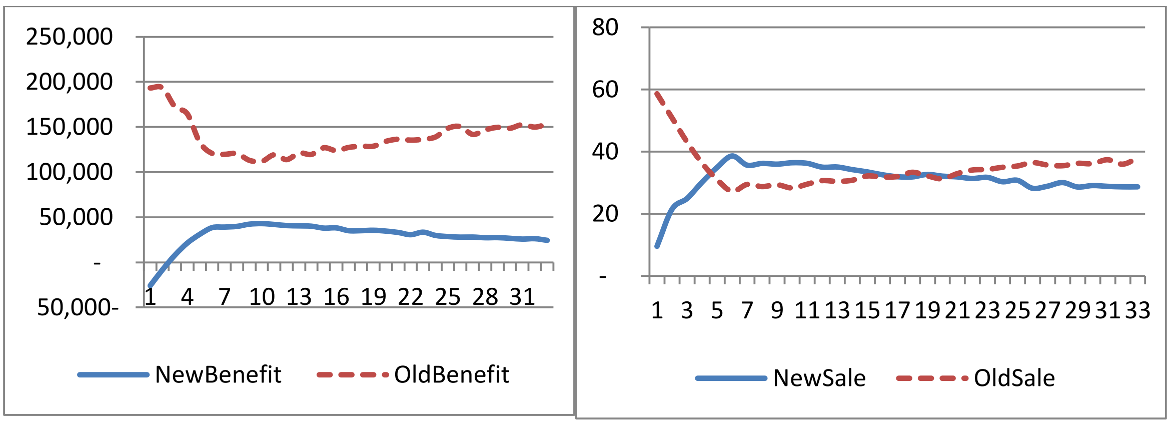

Figure 5: Profit and sales for policy 4 (decrease profit and attention to retailer)
NOTE: Profit: millions of Rials; sales: millions of cans.

In this policy, the main attention is on the retailers. The new producer reduces its profit by keeping a low wholesale price, which causes an increment in retailers' profit and determines a rational initial retail price for consumers. In this case, due to the high incentive of retailers and consumers to buy the new brand, seizing market share happens more quickly than in the other policies, and the new product gets 50% of the market share. However, because of the decline in the wholesale price and the reduction of profit for each product for the producer, despite the increment in sales amount, the total profit achieved doesn't increase and is equal to the first policy. This is despite the fact that if the sales amount decreases, as happened later, the risk of losing the benefit will be higher.

6.2. Changing producers' policies using game theory

Applying game theory to the model, producers can change their policies under changing profits and market conditions. After applying these changes in the model, the four policies were implemented again. After the changes, the wholesale prices for each brand in each policy are not just the initial value, and both producers can change the parameters during the model implementation. They can see the results, and in order to improve their profit function, they can decide to change the values of the wholesale prices. In this game, the players are the producers. Each game period is a 45-step simulation, and the decision of each player is determined based on the observation of profit changes in the previous two periods based on the Pricing Algorithm (Heppenstall et al., 2006) performed for retailer pricing before. Each player uses the algorithm to make the decision to change or maintain its wholesale price at the next level.

6.3. How do player actions affect the system, and what are the results?

Changes in the wholesale prices, which are the retailers' purchase costs, result in changes in retailers' profit margin and force them to react. Their reaction affects consumer behavior which in turn affects the Retailers' pricing decision and also their purchase behavior from producers. In fact, these changes are a result of wholesale price changes made by the producers, which has turned them into a casual loop. Changes in the sales and profit of the producers as changes in their situation in a game lead to their reactions in subsequent periods of the game. Because of the number of influencers and their type and timing effect, a complex game occurs between producers to increase their own market share and profit. What's interesting is that in the real world, similar to the same game, which details are illustrated in figure 6. The casual loop below is approved by 10 experts, including marketing researchers and business managers in Iran.

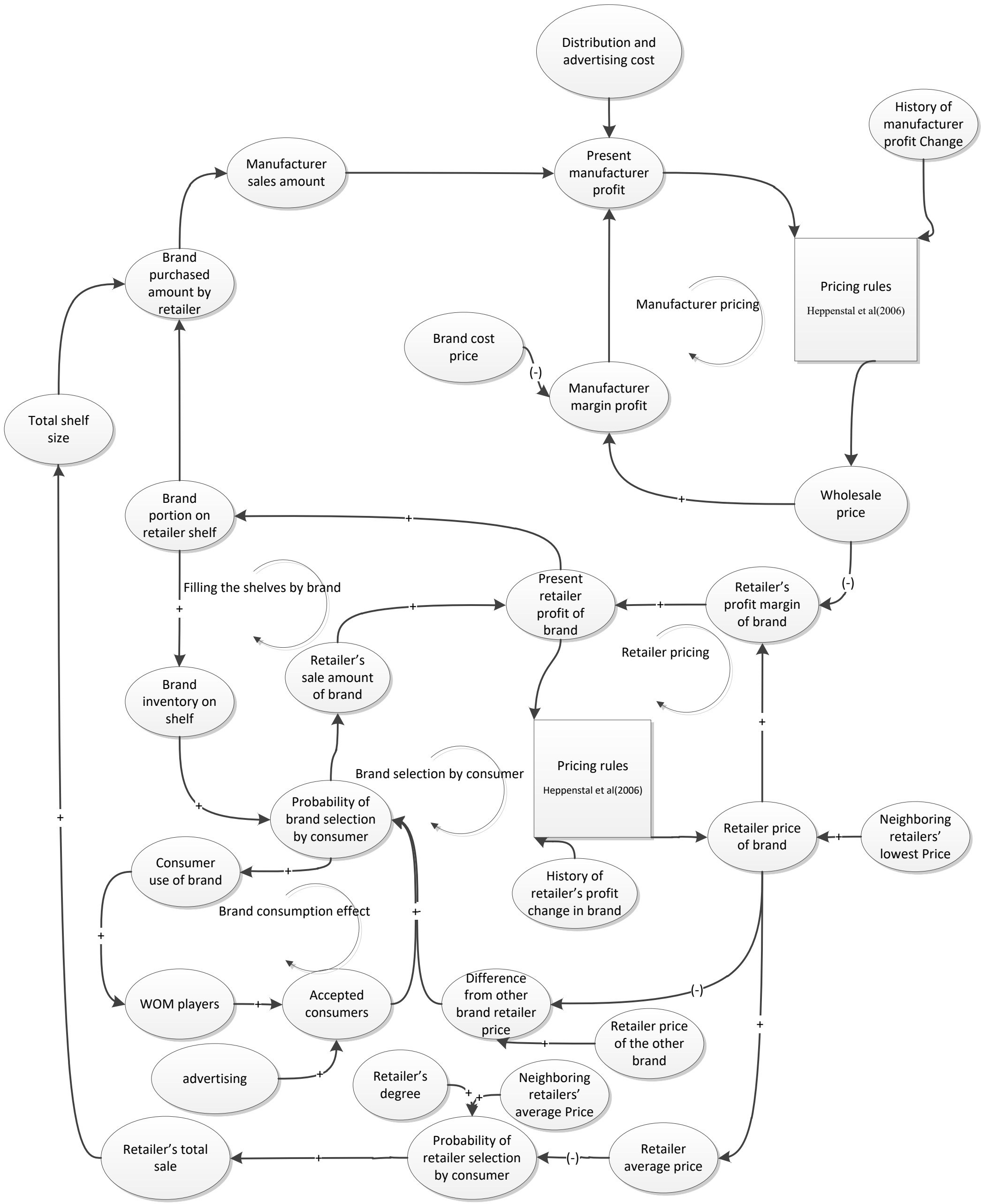

Figure 6: Casual chart for the model

It should be noted that producers throughout the game are aware only of their own sales and profits, and they react based only on their own situation, not the competitor's situation.

The profit function in each period is the net profit from the sale of the product by the producer during that period. It is calculated by the following formula:

Gross profit = (wholesale price – manufacturing actual cost) * total sales (4)

Net profit = gross profit - (advertising cost + distribution cost) (5)

After running the model for more than 1,000 periods, the total net profit obtained for each producer was calculated and displayed in the following table. It appears that after this period, the game has reached a balance condition because the situation of both producers is almost constant, and any reaction to a competitor's change may lead to a deterioration in profit. Table 4 shows the long-term results for each policy under a Nash equilibrium for the game.

Table 4 Long term result for each policy

Old Brand Benefit	New Brand Benefit	Policies
6,278,354,837	1,294,564,762	Policy 1
9,146,220,072	143,977,855	Policy 2
4,336,280,741	1,027,191,329	Policy 3
3,886,442,076	639,161,141-	Policy 4

Figures 7 to 10 show the results of the implemented policies after the application of game theory.

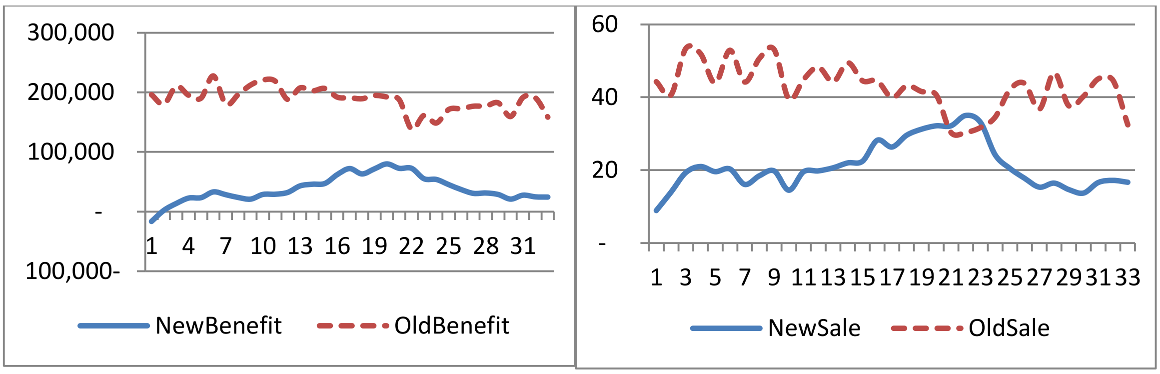

Figure 7: Profit and sales in policy 1 after application of game theory (decrease profit and attention to retailer)
NOTE: Profit: millions of rials; sales: millions of cans.

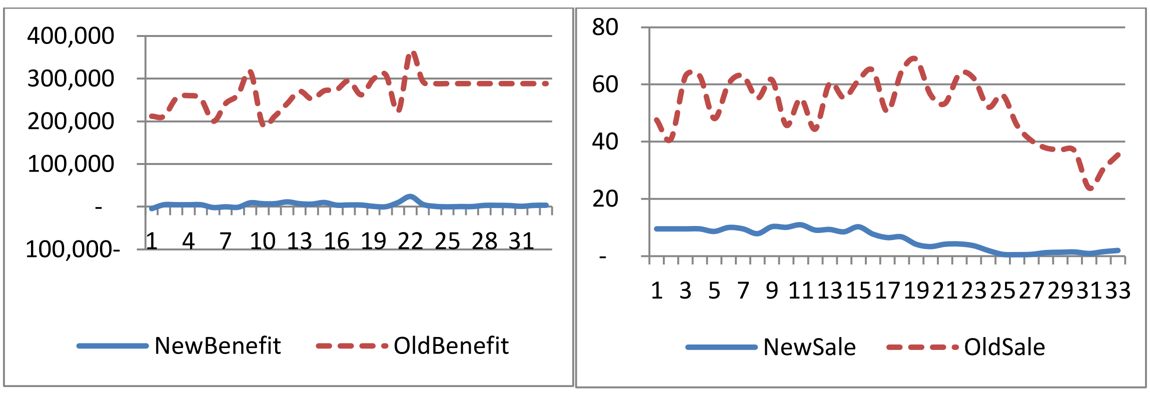

Figure 8: Profit and sales for policy 2 after application of game theory (regardless of the retailer's profit)
NOTE: Profit: millions of rials; sales: millions of cans.

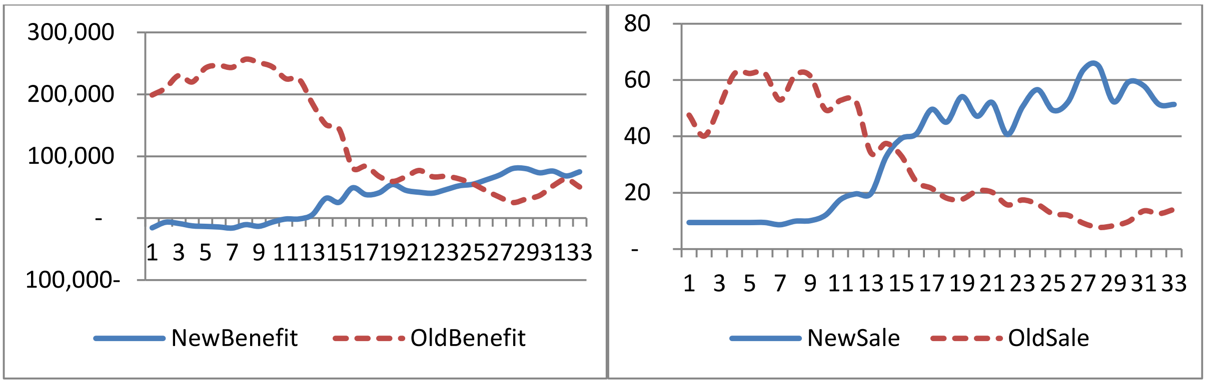

Figure 9: Profit and sales for policy 3 after application of game theory (attention to consumers)
NOTE: Profit: millions of rials; sales: millions of cans.

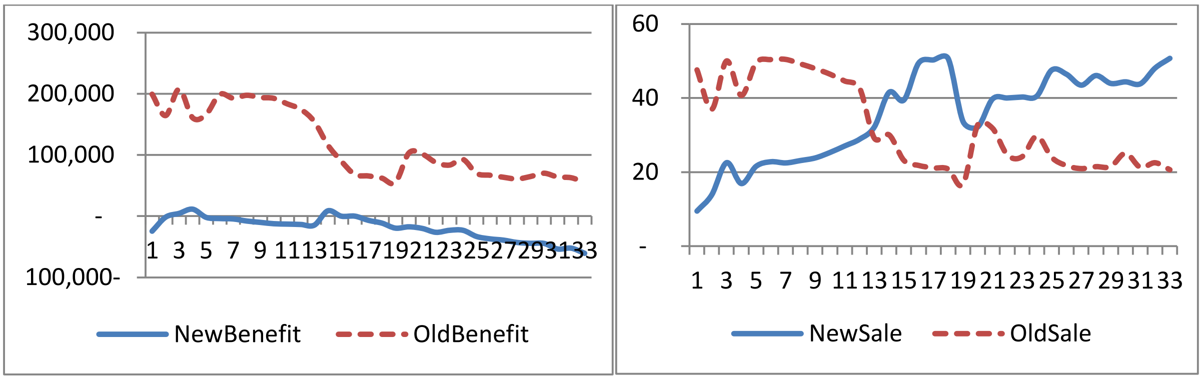

Figure 10: Profit and sales for policy 4 after application of game theory (decrease profit and attention to retailer)
NOTE: Profit: millions of rials; sales: millions of cans.

In policy 1, the new producer achieves the same profit gained before incorporating game theory into the model but with more fluctuations. In policy 2, there is not much difference in the results, but fluctuations are created for the main producer. In policy 3, the reactions of the main producer lead to profit reductions for him, while there are no changes in the results for the new producer. If the main producer does not react, its situation would be better. Policy 4, which apparently can be appealing to a new producer, in fact, is destructive and dangerous for both of them.

It is clear from the above results that policy 1 is the best; it simultaneously achieves a reasonable profit and market share for the new producer.

7. Conclusion

The present article attempts to examine issues that previous researchers did not pay enough attention to them at the same time (see Table 1). These include competitive environments, the effective role of retailers in the publishing process, repeat purchases after initial acceptance of innovation, and consideration of FMCG features in launching a new product. An agent-based model was proposed, considering different market decision-makers to cover the mentioned gaps. The agents are consumers who make decisions to stay loyal to brands and retailers in their shopping; Retailers, who have their own profit-based decision rules for repurchasing and pricing products they sell to consumers and compete with each other to attract more consumers; and producers, who have specific decision rules in competition with others to gain more market share and profit. After the construction of a communication network between consumers and retailers and within themselves, based on the principles of preferred networks, the model was run for 1,000 periods, and the behavior of consumers and retailers was simulated and evaluated. At the same time, competition between producers to increase their profits and the results of different policies for a new producer in a dynamic competitive environment were evaluated. The results show that to accurately predict the results of the launch of a new product, in addition to considering the principles of diffusion models, the behavior of key players in the post-release period and in the market repurchase process must be considered. Also, decisions about whether to implement any changes should consider the fact that the effect of changes in the market is not linear but is the result of decisions made by different decision-makers at different levels. The present paper aimed to find the best policy for a producer who wants to launch a new product into the market when a similar product is already in the market. The results show that disregarding retailers is problematic in the diffusion process, and paying attention only to consumers can be catastrophic.

From the managerial aspects of the results of this study, it can be pointed out that for the successful launch of a new brand, depending on the price and position of competitors, the interests of retailers and consumers must be considered simultaneously. The developed DSS software can also be used by administrators as a tool to adjust parameter values such as margins and costs.

The present paper discusses only the effect of wholesale price changes by producers. Future research could consider other factors such as timing, amounts, and media advertising coverage regions. In addition, in the present paper, the target areas for product distribution by producers, sales visit periods, and product shipment to retailer costs were assumed to be constant, which could be considered in implementing a policy in the proposed and similar models. Finally, it is suggested that this model be developed, including more producers.

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A System Dynamics Approach to Sustainable Business Model Transformation: A Manufacturing Case

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ABSTRACT

Corporates and industries must make their businesses work more sustainably to benefit from a sustainable economy. Hence, corporate leaders are in a challenge of decision-making about transforming their business logic through innovative sustainable business models. The involvement of business models and environmental issues requires dealing with complexities that arise from a large number of interrelated actors as well as the dynamic nature of environmental issues. Early in its literature review, this paper summarizes the innovations and strategies for sustainable business model transformation. Most importantly, this paper proposes using System Dynamics (SD) modeling as a decision support tool that could support business cases with sustainability concerns. Later in this paper, a plastics manufacturer trying to utilize recycling and reuse in its production process exemplifies our discussion. The implications are then generalized to support managerial decisions raised by companies and corporations willing to integrate sustainability into their business models. In the case mentioned in this article, System Dynamics modeling and simulation helped managers deal with the uncertainties regarding their decisions, demonstrating how a sustainable business model could be adapted to a working production system. The simulation results show that a 32 percent raise in the recycling and reuse capacity in the manufacturing company could significantly improve the company's green image, and the quality could be controlled above 85 percent. Besides, savings from recycling and reuse will compensate for the investment in the transformation plan in 55 months.

Keywords

Business Model Innovation, Sustainability, System Dynamics, Decision Support

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1. Introduction

Business leaders have always struggled to maintain their businesses sustainably at the individual, organizational, and social levels (Schaltegger et al., 2016a). To improve sustainability performance, business leaders must make fundamental changes in their business logic (Abdelkafi and Täuscher, 2016). In other words, to shift the concerns in businesses towards environmental and social issues, the underlying business models have to be transformed and become sustainability-oriented (Schaltegger et al., 2016b). Hence, business leaders face complex decisions that must be supported by proper decision support tools (Schaltegger et al., 2012).

In recent years, there have been great concerns about sustainability among industries. Sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). In other words, sustainable development maximizes economic advancements while taking care of long-term environmental values without making tradeoffs between environmental sustainability and economic development (Emas, 2015). Admittedly, the role of industrial and corporate sustainability is inevitable in the sustainability of the national and global economic systems (Tonelli et al., 2013). In other words, global sustainable development is impossible without the sustainable development of corporations (Schaltegger et al., 2012). Yet, businesses are under growing regulatory pressure to move towards environment-friendly products and services (Moultrie et al., 2015). By the same token, governmental incentives depict more promising outlooks for sustainable businesses from an economic, social, and environmental point of view (Melkonyan et al., 2017); to such a degree that the idea of sustainability is being regarded as a competitive advantage. A partial solution to such a problem is the concept of Circular Economy, that is, in this paper's case, trying to close the resource loops through reuse, remanufacturing, and recycling (Geissdoerfer et al., 2018). This strategy could be applied to manufacturing companies and results in a circular flow of resources (Bocken et al., 2016)

In recent years, business models have attracted great notice from researchers and practitioners in the field of sustainability management (Geissdoerfer et al., 2018). Perhaps that is because to attain sustainability in business; the business models should be subject to change and evolution to maintain or increase economic gains while positively affecting the environment and society (Schaltegger et al., 2016a). The business model has been a prevalent concept in management science in recent two decades (Zott et al., 2011). A business model is the design and structure of an organization's value creation, capture, and delivery mechanisms (Teece, 2010). Business models with sustainability concerns are called terms like sustainable business models (SBM), sustainability business models, or business models for sustainability (BMfS) (Abdelkafi and Täuscher, 2016). The first contributions to sustainable business models were mainly focused on organizational structure and culture (Stubbs and Cocklin, 2008), while a growing number of academic works focused on innovations and strategies for sustainable business models (Schaltegger et al., 2016b). Business model innovation (SBMI) is exploring, revising, adjusting, developing, and innovating a business model with sustainability considerations (Geissdoerfer et al., 2018). Sustainable business model strategies (SBMS) or archetypes are groupings of solutions that could be used to build a sustainable business model (Bocken et al., 2014).

Regarding decision-making, managers choose the business model according to corporate visions and strategies (Schaltegger et al., 2012); business strategists usually modify their business models with economic prospects, but their decisions have broader consequences because of the inevitable interactions between business and the environment. Regarding the number and the changing nature of the forces affecting such problems, we can say the problems with sustainability concerns are complex. Business leaders need to employ certain tools for formulating and solving complex problems because the human capacity for dealing with such problems is very small (Simon, 1957). Decision-making for complex problems is quite challenging, and one of the most suitable decision tools for dealing with complex problems is Systems Dynamics (SD) (Sterman, 2000).

The case represented here is a plastic manufacturing company that is on its way to shifting its business model toward a cleaner and more sustainable one. The changes in the business model entail modifications in product design, manufacturing process, and material lifecycle to facilitate recycling and material reuse. The customized plastic recycling and reuse process is being integrated into the production process to enable the factory to recycle material and reuse parts besides its production under one roof. The dynamic problem here is to find out whether or not and how a mid-term or long-term approach to financing a sustainable business model will reach a breakeven point, after which the business could enjoy the economic returns (the dynamic behavior of total revenues and costs of the company are of high importance in this regard). In the mentioned case, SD modeling enables the company's managers and strategists to view the consequences of their decisions regarding sustainable business model transformation. The dynamic modeling of the case and simulation of the alternative futures

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could have implications (as a decision support tool) for corporate decision-makers and assist them in developing innovative business models. Moreover, the impact of governmental support of sustainability transformation programs is studied by including factors like governmental incentives in the forms of loans and Ecotax in the dynamic model.

This paper is organized as follows. The following section reviews previous research works about sustainable business models, innovations, strategies for business model transformations, and the relevant decision models. This section summarizes the sustainable business model transformation innovations and strategies in a useful and preferable way. After that, the research methodology is explained, and a brief review of the system dynamics methodology is reported. The third section represents the conceptual model using causal loop diagrams. This section and the next one propose a decision support framework for sustainable business model transformation for a plastic manufacturing company. In the next section of the paper, the relationships among the variables are explained in mathematical terms in the form of a stock-flow diagram. The last section entails a discussion and implications that could be derived from this study and used in practice and research.

2. Literature review

Numerous academic efforts have been toward building business cases that try to support decisions related to sustainability under different terminology and conceptualizations. The concept of Sustainability Accounting, for example, was raised by Bebbington and Gray ((Bebbington and Gray, 2001; Bebbington et al., 2001; Gray and Bebbington, 2000), and developed in the works of Schaltegger, Wagner, Bennett, and Burritt (Schaltegger et al., 2006; Schaltegger and Burritt, 2010; Schaltegger and Wagner, 2006). Following the emergence of a considerable body of literature that concentrated on creating economic value while increasing corporate environmental and social performance (e.g., Dyllick and Hockerts, 2002; Epstein and Roy, 2003; Schaltegger and Wagner, 2006), Schaltegger et al. (2012) proposed a framework for business model innovation. Some works proposed decision support frameworks using Multi-Criteria Decision Making (MCDM) (Azapagic and Perdan, 2010, 2005; Gommes et al., 2012) regarding the three dimensions of sustainability (namely, financial, social, and economic). There have also been practical approaches; for instance, the development of decision-support systems to ease the adoption of the best sustainable energy practices (Parraguez Ruiz and Maier, 2018) or multi-criteria decision support for sustainability assessment of manufacturing system reuse (Ziout et al., 2013).

Most importantly, several academic works utilized SD modeling to deal with business model innovations associated with sustainability. Abdelkafi and Täuscher (2015) investigated the characteristics of robust business models from an SD perspective. Then, Abdelkafi and Täuscher (2016) employed the graphical notations of SD to model the dynamics of the various players in a Business Model for Sustainability (BMfS). Asif et al. (2016) used a simulation tool based on SD and Agent-Based modeling to define and analyze the performance of circular product systems. In a similar work, Rodrigues et al. (2017a) used an SD approach to propose a simulation-based business case for Ecodesign implementation - a sustainability-oriented business model innovation. Later, Täuscher and Abdelkafi (2018) built a simulation model that connects different dimensions of the Business Model for Sustainability. The focal point of this paper is the application of system dynamics modeling in building decision support for sustainability-related decisions.

Regarding a review by Geissdoerfer et al. (2018), different approaches taken by the researchers around the issue of sustainable business models are mapped with several types of research from the literature. Table 1 illustrates a typology for sustainable business models (SBM) by separating their Sustainable Business Model (SBM) Types, Sustainable Business Model Innovation (SBMI) types, and Sustainable Business Model Strategies (SBMS). This categorization could help develop new paths or configurations for sustainable business model innovation (Bocken et al., 2014).

Using Table 1, we have sorted the other research works around sustainable business models. Nearly all research works presented here have used System Dynamics modeling as a decision support tool.

Table 1. A Typology of Sustainable Business Models based on Geissdoerfer et al.(2018)

Categorization	Example	Abbr.	Description
Sustainable Business Model Innovation Type (SBMI)	Sustainable Start-Ups	SSU	Creating a new organization with a sustainable business model
	Sustainable Business Model Transformation	SBMT	Transforming the current business model into a sustainable one
	Sustainable Business Model Diversification	SBMD	Adding a sustainable business model to the organization without making major changes to the original business model
	Sustainable Business Model Acquisition	SBMA	Identifying, acquiring, and integrating a sustainable business model into the organization
Sustainable Business Model Type (SBM)	Circular Business Model	CBM	BMs that are closing, slowing, or narrowing the resource loops
	Social Enterprises	SE	BMs that generate profits from economic activity or reinvest them totally so that making a social impact
	Bottom of the Pyramid Solutions	BPS	BMs that target the customers at the bottom of the income pyramid
	Product-Service Systems	PSS	BMs that integrate products and services and offer them to customers
Sustainable Business Model Strategies (SBMS)	Maximize Material & Energy Efficiency	EFF	Material-efficient
	Closing Resource Loops	CRL	Closing the resource loops through reuse, remanufacturing, and recycling
	Substitute with Renewables & Natural Resources	REN	Replacing non-renewable resources with renewable ones, and artificial processes with natural ones
	Deliver Functionality rather than Ownership	FUNC	Offering the user the required functionality without giving them ownership of the product that provides the service
	Adopt a Stewardship Role	STEW	Protecting natural systems by introducing a gatekeeper that controls or motivates certain behaviors
	Encourage Sufficiency	SUFF	Informing and motivating less consumption
	Repurpose for the Society or the Environment	REP	Utilizing organizational resources to create societal or environmental benefits
	Inclusive Value Creation	IVC	Delivering value to formerly unattended stakeholders by including them in the value creation process
	Develop Sustainable Scale-Up Solutions	SUS	Scaling sustainable solutions and technologies

Table 2 lists research works that revolve around sustainable business models, and it also addresses the type of sustainable business model (SBM), sustainable business model innovation (SBMI), and the enable business model innovation (SBMI) for each research. As shown in Table 2, no other research has yet worked on sustainable business models in the plastic industry.

Table 2. Research Works on the topic of Sustainable Business Models

Research Study	SBM	SBMI	SBMS	Case Study	Modeling
Abdelkafi and Täuscher (2015)	CBM	SSU	EFF	Online Retailing	SD
Abdelkafi and Täuscher (2016)	SE	SSU	SUS	Crowd Funding	SD
Asif et al., (2016)	CBM	SBMT	CRL	Misc.	AB* - SD
Rodrigues et al. (2017b)	-	-	Misc.	Misc.	SD
Hutchinson and Walker (2012)	CBM	SBMA	EFF	Fast Food	None
Duran-Encalada and Paucar-Caceres (2012)	CBM	SBMD	EFF CRL REN	Oil Production	SD
Moellers et al., (2019)	PSS	SBMD SBMA	FUNC	Automotive	SD
Gomez-Segura et al., (2019)	CBM	SBMA	EFF	Print Packaging Manufacturing	SD
Chen et al., (2018)	SE	SSU	SUS	Crowd Funding	SD
Mansilha et al., (2019)	CBM	SBMA	EFF REN	Broiler Production	SD
Geissdoerfer and Weerdmeester, (2019)	CBM	SBMD	CRL FUNC	Process and Manufacturing	None

*AB= Agent-Based

3. Research methodology

The paradigm that governs this research is that of shifting the economic view in our businesses to a more sustainable one. That means we should make innovations to turn our business models sustainable. Consequently, we face complex decisions while dealing with different scenarios that might happen as a result of the decisions we make about the business model. Supporting such decisions requires dealing with complexities associated with sustainability issues and the company's business model (Schaltegger et al., 2012). Thus, a dynamic approach must be employed to define and understand the evolution of business models (Demil and Lecocq, 2010). There are some limits on human faculty to handle complex decisions (Simon, 1957); therefore, to tackle dynamic complexity and multiplicity of influential inter-related actors in the process of decision making, we need decision support tools based on systems thinking and system dynamics (Sterman, 2000). In some cases, the dynamic nature of planning leads managers to employ dynamic decision support tools to such an extent that using static approaches could mislead managers in selecting their strategies (Hosseini et al., 2019). System Dynamics (SD) is known as an ideal methodology for modeling complex dynamic problems (Sterman, 2000), especially for strategic decision-making in the manufacturing sector (Rafiei et al., 2014). In this paper, we used SD modeling to support the decisions surrounding a practical approach to a sustainable business model (SBM) in a manufacturing company.

The presented model is based on the production system in a case study. In addition, the structure of the model in decision-making parts is based on the interviews with the experts and decision-makers in the company about the processes under study. Moreover, the data used in the simulation is gathered from the company's official reports and ERP system or inferred from them.

The model developed in this paper tries to offer business owners and strategic decision-makers insight into the probable consequences of their sustainability-oriented decisions. Moreover, the results from this research contribute to the analysis of different possible sustainable business model options suitable for use in the plastic industry, especially those with a tendency to employ a circular economy approach.

Figure 1 represents the main steps of this study based on the system dynamics methodology. In the first step, the previous works are reviewed to determine an appropriate set of variables dealing with the sustainable business model transformation proposed for the case study. Next, the problem is analyzed to select the variables we focus on throughout the study. In the third step, we have formulated a conceptual framework in which the main balancing and reinforcing loops that reflect the dynamics of the variables are clarified through causal loop diagrams (CLD). In the next step, gathering historical data of the system's variables, a mathematical model is developed to simulate the consequences of different business model design options in the case under study. Before system simulation, the validation of the model is tested in step five. In step 6, the system is simulated with 3 different sustainable business model design options. Finally, the results from the previous step are analyzed, and the system's behavior is probed under different scenarios.

It is to be mentioned that the models with the data used in simulations are developed concerning the manufacturing process of a real plastic manufacturing company. In this article, the authors have simplified the model intending to increase its objectivity and applicability to similar situations and, most importantly, propose a framework for supporting decisions in sustainable business model transformation.

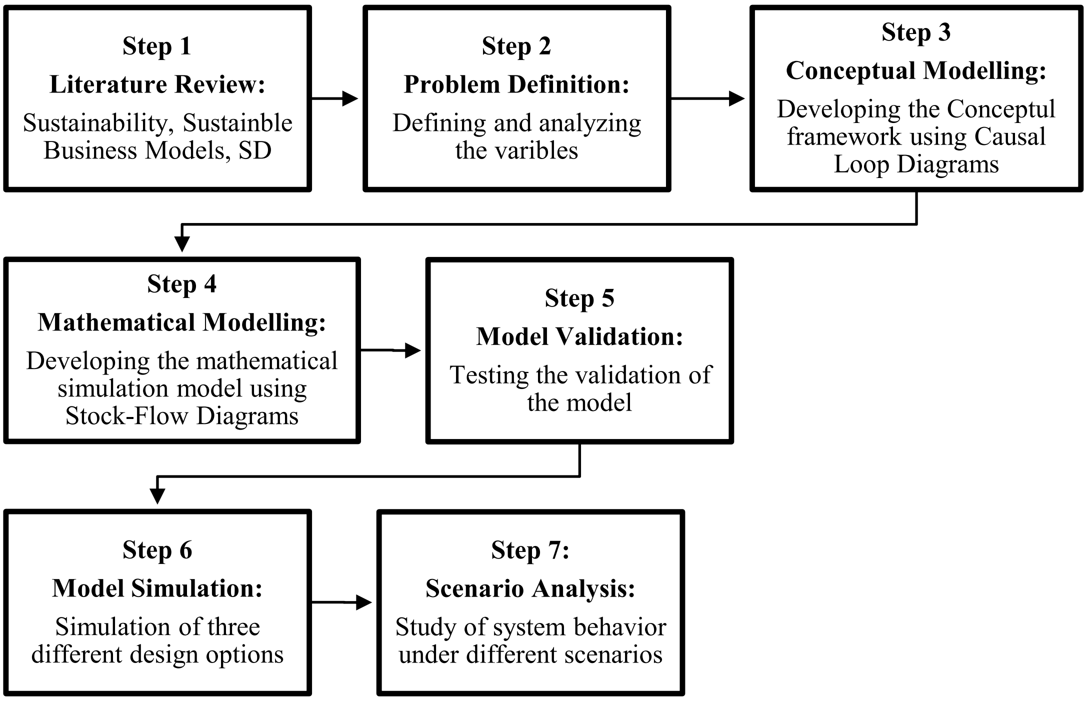

Figure 1. Research Process

4. The proposed model

This section depicts the model under discussion using causal loop diagrams (CLD). Causal loop diagrams are used to show the causal relations between system components and the feedback structure within the system (Sterman, 2000).

It is to be mentioned that the recycling process normally takes place outside the manufacturing plant. More specifically, recyclable plastic parts are normally gathered, refined, cleaned, and turned into second-hand granules in plastic recycling plants or anywhere outside the manufacturing plants. However, in the case study, a different approach is employed in which material recycling occurs at the manufacturing company. This aberrance is based on at least two reasons. Firstly and most importantly, the factory under study is located in Iran, a developing country that lacks an effective recycling system capable of collecting, refining, and reliably reproducing high-quality plastic granules. In Iran, the plastic recycling system is not integrated, and the output material is of inferior quality. The second reason for implementing this approach is that the availability of recyclable material and reusable parts create some opportunities for plastic manufacturers like this one, and by using these opportunities, they could benefit from a cheaper and more reliable supply of reusable parts and recyclable materials that could be used to build a customized reuse and recycling process at the same location in an integrated manufacturing process.

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The system under study comprises manufacturing, supply chain, storage, and management subsystems. The model's boundary is limited to the functions and segments within these subsystems that have a material or data connection to the recycling and reuse components and their business sides.

The factory understudy manufactures Attached Lid Containers (ALC) and heavy-duty plastic pallets using High-Density Polyethylene (HDPE) and Polypropylene (PP). These products are used in different industries and are discarded after a period because of over-usage or misusage. This continuous flow of overused or discarded products stacked in the users' place creates an opportunity for the manufacturer to access reusable and recyclable material. Using the manufacturer's products as input to their recycling and reuse process has many advantages, including access to a defined and controllable used material and parts in terms of quality and design. Moreover, acquiring materials and parts from a customer as a supplier to the recycling and reuse process can create other win-win opportunities for both parties.

As in Figure 2, a rise in production rate increases the sales rate – providing that the market demand is high enough. Consequently, the number of products in use by the end-users goes up. At this point, if the collecting capacity of the used product comprised of the machinery, human resource, and the running process is in place, it can result in a rise in used product collection rates, naturally after a delay that corresponds to the time that the product is under use by the user. Collected parts will then go through the verification process.

$$Pr = Min(\frac{Raw\ Material}{Parts\ Inventory} \times \frac{Raw\ Material}{Parts\ Consumption\ Ratio}, Compay's\ Market\ Share \times Total\ Product\ Demand) \quad (1)$$

$$FPInUse = Sales + Competitors'Sales - Product\ Disposal \quad (2)$$

Pr: Production rate

FPInUse: Final Product in Use

Verification is a collective name given to the process of preparing the collected material for recycling and reuse. The verification process includes refining, cleaning, and verifying the collected used products and parts. We decided to summarize all these processes in just one process in our model because the materials and parts that are gathered and brought to the recycling site are of high quality. There is more verification than refining, sorting, and cleaning. Then, depending on the company's capacity for verifying the reusable parts, bigger numbers of collected parts increase the volume of the verified reusable and recyclable materials and parts that adds to the inventory of materials and parts. This inventory is then used in the production process. Of course, if the inventory level of materials and parts falls below the desired inventory, purchasing first-hand materials fix the shortage.

$$RRr = Min(Recycling\ Capacity \times 20000, Recycling\ Yield \times VUP) \quad (3)$$

$$VUP = Approval\ rate - RRr - Unusable\ Material \quad (4)$$

RRr: Recycling/Reuse rate

VUP: Verified Used Products for Recycling/Reuse

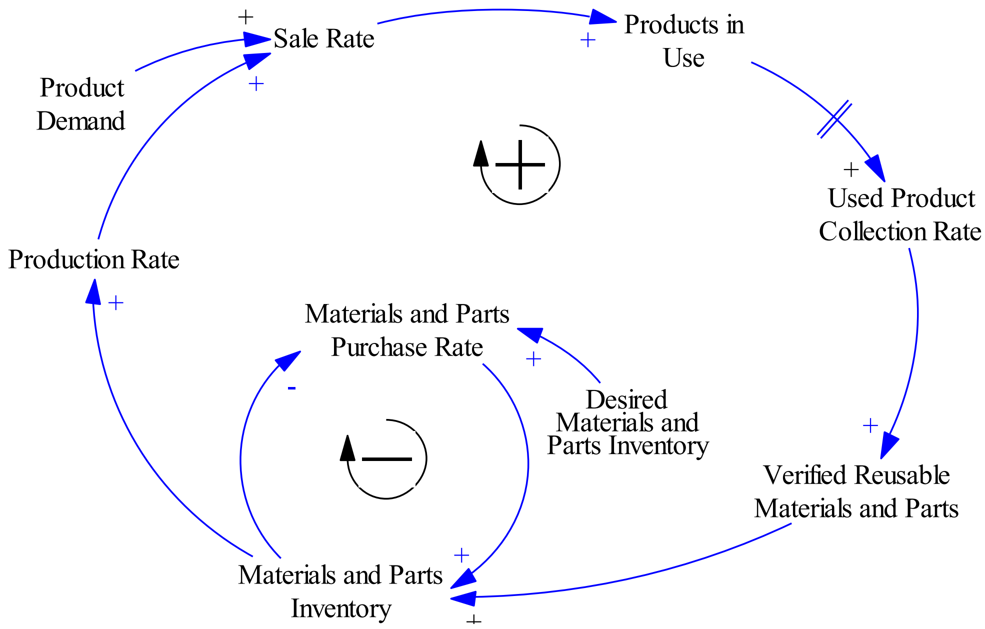

Figure 2. Recycling and Reuse Process

Figure 3 illustrates that as the percentage of recycled materials and reused parts rises, the quality of the products goes down and, in this way, controls the demand for the product. On the other hand, a high percentage of recycled materials and reused parts raise the green image of the company and incites higher demands. It should be noticed that the use of recycling and reuse cannot go further than accepted thresholds, which are generally deducted from experience, quality limits, and technology considerations.

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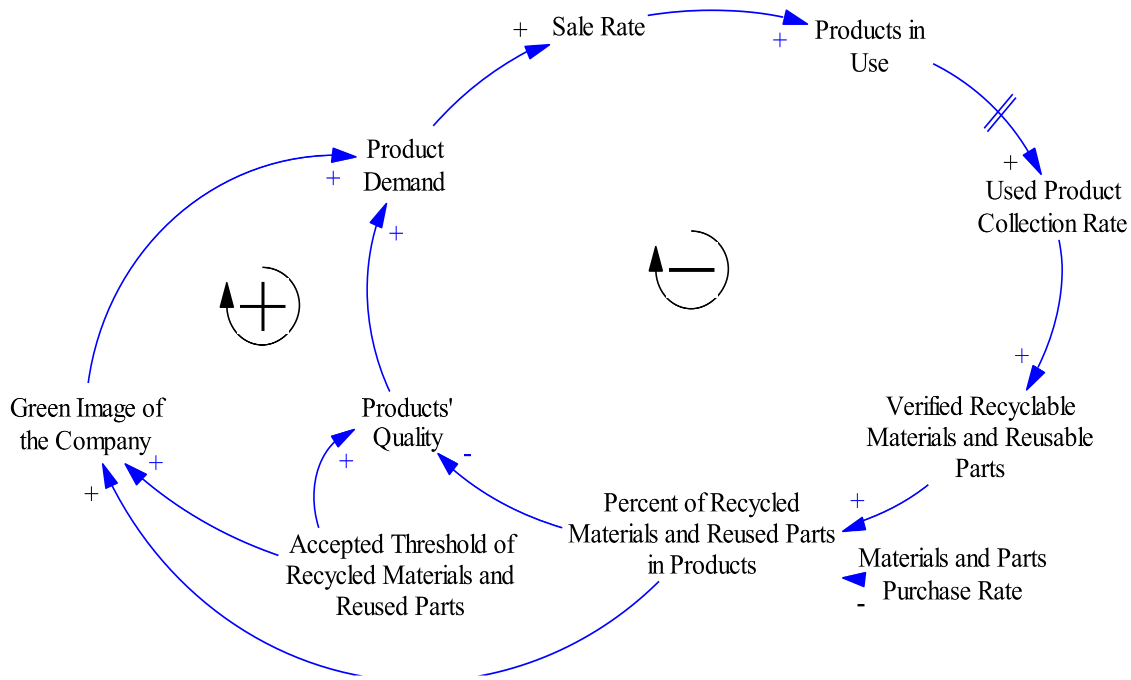

Figure 3. CLD of Production and Green Image

Figure 4 depicts some governmental and managerial issues concerning recycling and reuse. As recycling and reuse increase in the company, more governmental incentives would be available. On the other hand, purchasing first-hand (non-recycled) material might impose some pollution tax (Ecotax) on the company. These two factors may provoke the management's concerns about sustainability-related issues. As such concerns grow, the company's decision-makers might consider shifting to a more sustainable business model, and as a result, recycling and reuse capacity could expand. Besides that, there might be a higher market demand because of increased branding activities and the promotion of the green image of the company and its products.

$$SusBudg = a \times (1 + MCS) \times Financial\ Resources \quad (5)$$

$$Received\ Financial\ Recources = RRr \times Unit\ Financial\ Incentive \quad (6)$$

MCS: Management's Concerns for Sustainability

SusBudg: Budget for Sustainability

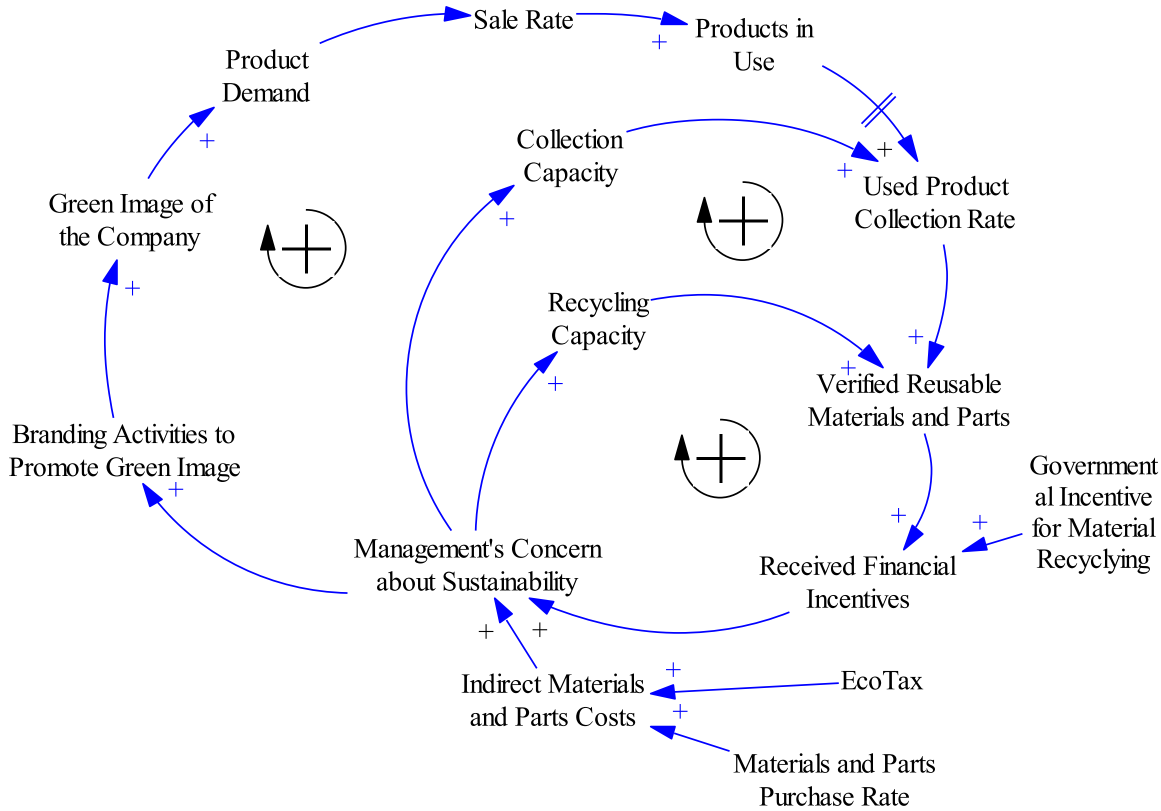

Figure 4. Economic Considerations of Recycling

Figure 5 illustrates the main financial considerations of recycling and reuse in the case. As the sale of products increases, the total revenues - including sales revenue and governmental incentives- grow higher. The total costs entail the cost of direct and indirect material and parts- the production cost and recycling and reuse costs. Costs and revenues affect a company's profit, and increasing profit increases the budget for developing recycling and reuse infrastructure and branding and advertising.

$$
\begin{aligned}
&Financial\ Resources\ = Received\ Financial\ Incentives + Revenues\ from\ Sales - \\
&Total\ Costs \\
&Total\ Costs = Production\ Cost + Collection\ Cost + Raw\ Material\ Supply\ Cost \\
&+ Recycling\ Cost + Sustainable\ Business\ Model\ Development\ Cost
\end{aligned}
\tag{7}
$$

In System Dynamics terms, there is a reinforcing loop on the revenue side, which could be balanced by the balancing loop on the costs side. Also, in the previous CLDs, there is a reinforcing loop on the recycling and reuse infrastructure, which could be limited by the company's thresholds.

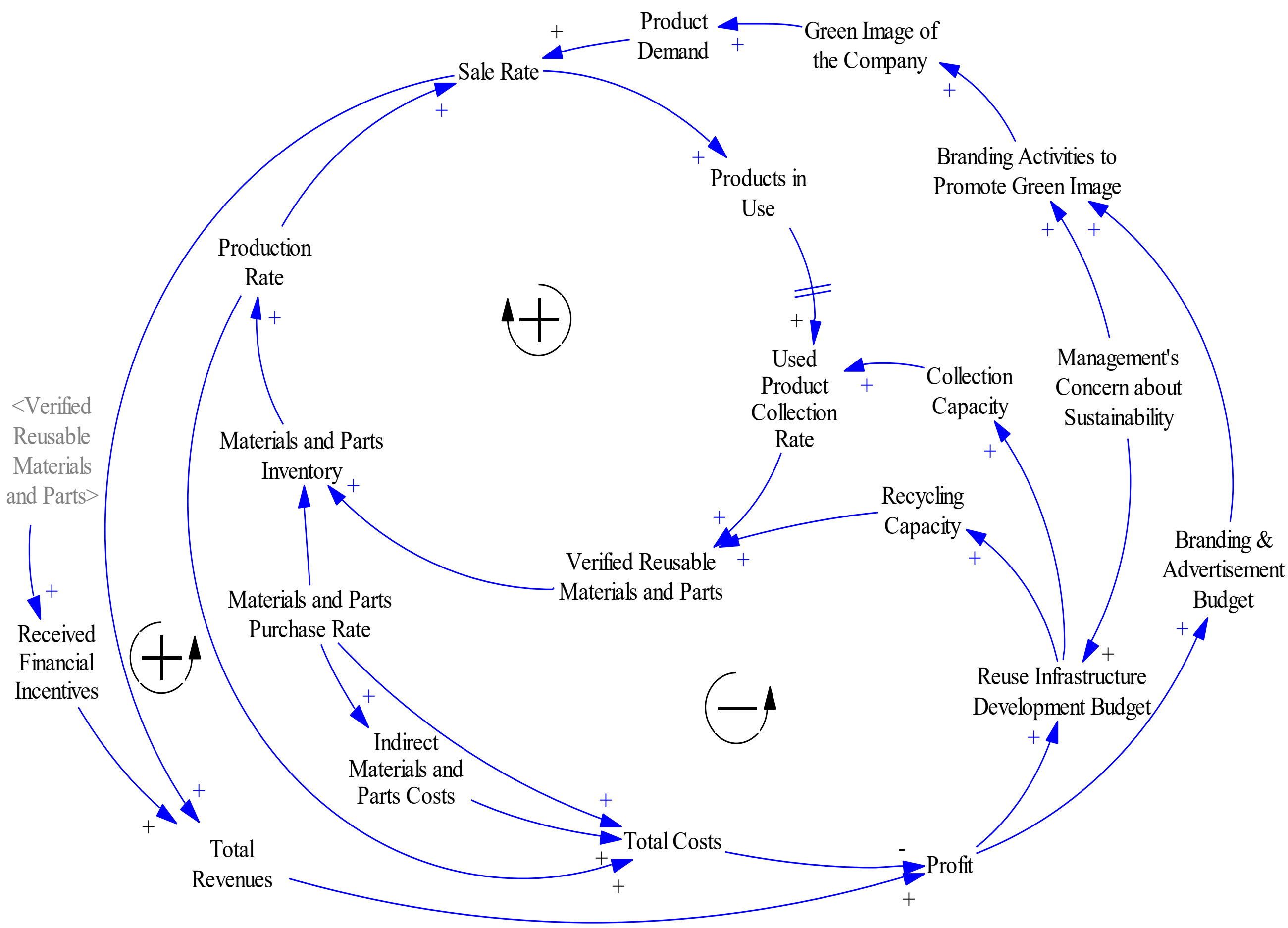

Figure 5. Financial Considerations

5. The simulation model

In this section, the mathematical model is illustrated and explained (Figure 6). Causal loop diagrams illustrate the feedback structure of systems, while stock and flow diagrams emphasize the underlying mathematical relationships in a system (Sterman, 2000).

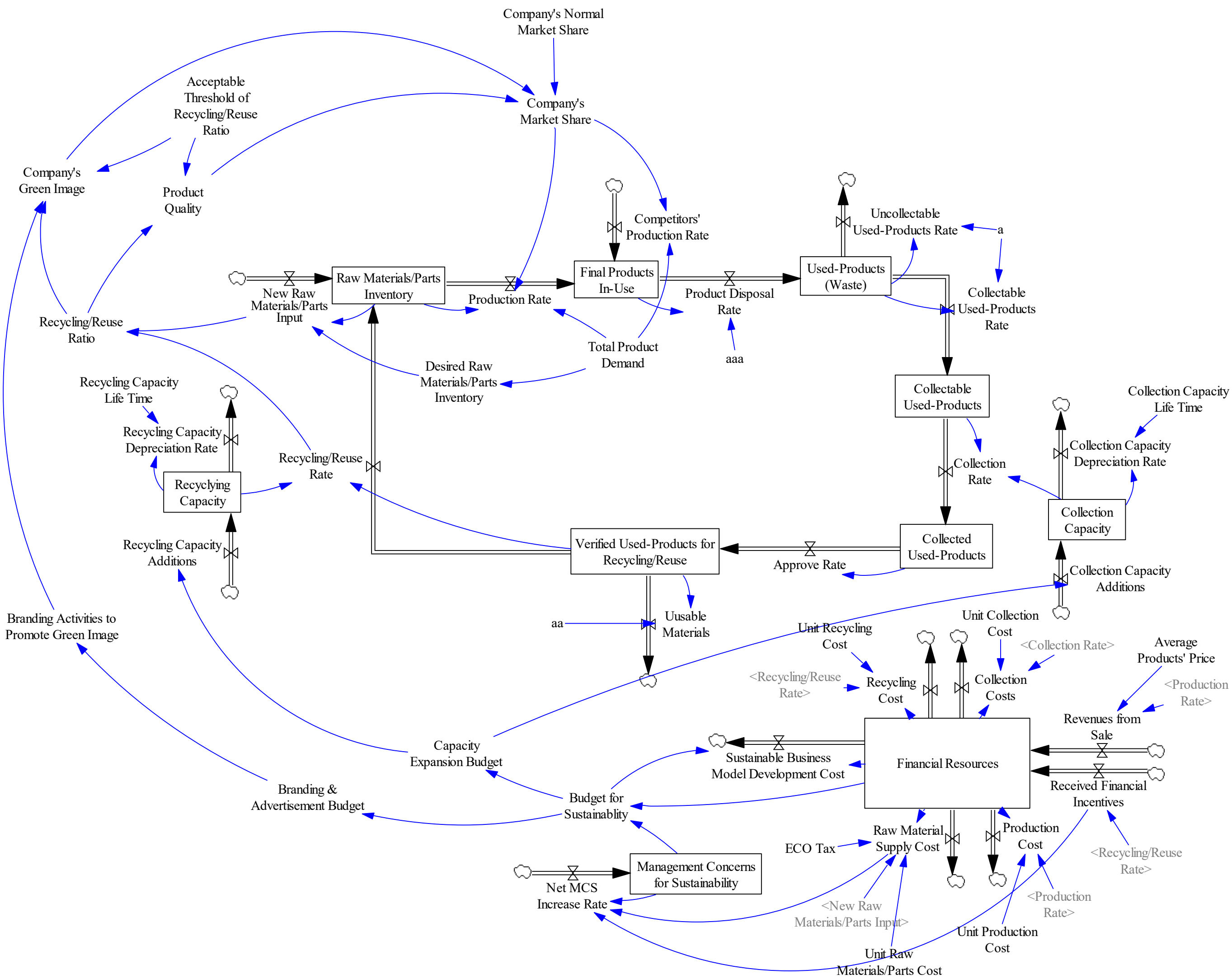

Figure 6. Stock and flow diagram

The innovations have caused many changes in the company's business model; therefore, the Stock-flow diagram looks different in several ways. First, the management concerns about sustainability create a budget line for maintaining a recycling and reuse capacity and branding activities that promote the company's green image. Second, recycling and reusing close the material flow and allow the waste to be used in the production process. Third, the company's financial resources are affected in many ways, the most important of which is the income mostly from savings of new material, the costs of collecting and processing used products, and the government incentives that help to make such a change economically feasible.

In this case, the management's concerns about sustainability triggered the change. The transformation into a more sustainable business model yields changes in different factory parts. In addition, different parts of the company must work in harmony. In the case under study, it all started with defining a budget line by which plastic collection, storage, and processing became possible. Making this change requires the investments to create, modify and coordinate supply chains and production lines; hence, it needs initial investments. In addition, to take advantage of the improved green image of the company in the future, some branding activities may start immediately that also need investment. From a financial point of view, transforming to a sustainable business model is a long-term investment. In other words, there is a delay between investing money in a sustainable business model and receiving its financial benefits in terms of lower material costs or an improved green image of the brand.

After customers have used the final products, they are collected by the factory's supply chain, which has gone through some modifications as part of the business model transformation. Our model calculates the collection rate based on the collectible used products and the collection capacity.

$$Collection\ Rate = \min(Collectable\ Used\ Products, Collection\ Capacity * 50000) \quad (8)$$

Final products of the factory that are in use by the end-users transform into used products with a product disposal rate. The product disposal rate is calculated based on the product lifetime.

$$Product\ Disposal\ Rate = \frac{Final\ Products\ In - Use}{Product\ Lifetime} \quad (9)$$

Only a part of the used-products stock is collectible, so the used products are stocked into collectible used products with a collectability rate. After that, only collectible used products are stocked in collected used products, following the collection rate. A portion of collected used products is verified with a verification rate maintained according to the company's quality considerations. After the parts are collected, they go through several preparation steps summarized in our model under the name of verification. The verified used products then go through the recycling/reuse process, the output of which is the raw materials/parts stocked in the inventory. Finally, the prepared used parts and materials are fed into the production line, closing the production loop. Another input to this inventory is, of course, first-hand materials/parts. Only after the recycled material or parts are used in the production process do the financial benefits emerge in the model. For some time, the benefits compensate for the initial investment of business model transformation; after that, the company could benefit financially from making its business model sustainable. There are some other forms of financial benefits in the model, for instance, government incentives and the benefits from the company's green image. These side benefits could come in different forms and, if managed correctly, could add to the financial rewards of the sustainable business model.

6. Simulation results

In this part, we discuss the differences between the original business model (base run) and the transformed sustainable business model (SBM Scenario). It is obvious in Figure 7 that the ratio of recycling and reuse grows to around 32 percent in the SBM scenario.

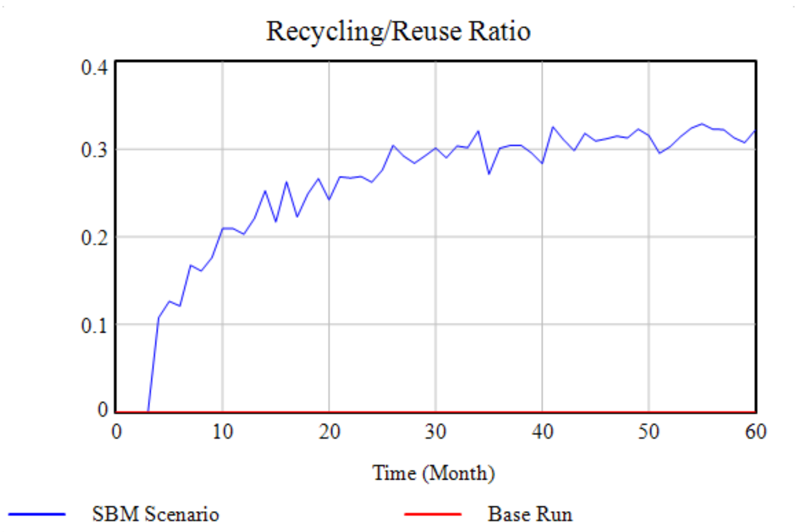

Figure 7. Recycling/Reuse ratio

In figure 8, although there has been a slight decline in the quality of products in the SBM scenario, the quality level of the products is maintained and controlled at a steady rate above 85 percent.

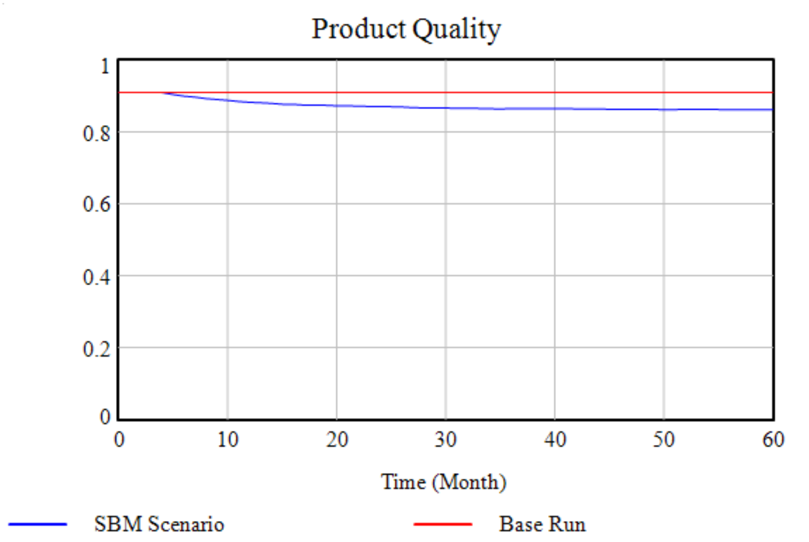

Figure 8. Product quality

In figure 9, it is obvious that the company's green image has increased as a result of business model transformation and branding activities and remains for a couple of years at a high level, giving the company enough time to improve the brand.

Figure 9. Company's green image

As in figure 10, the production rate increases after establishing the sustainable business model because, in the SBM scenario, the company enjoys an extended production capacity that can respond to the higher market demands caused by an improved brand in the light of the company's green image.

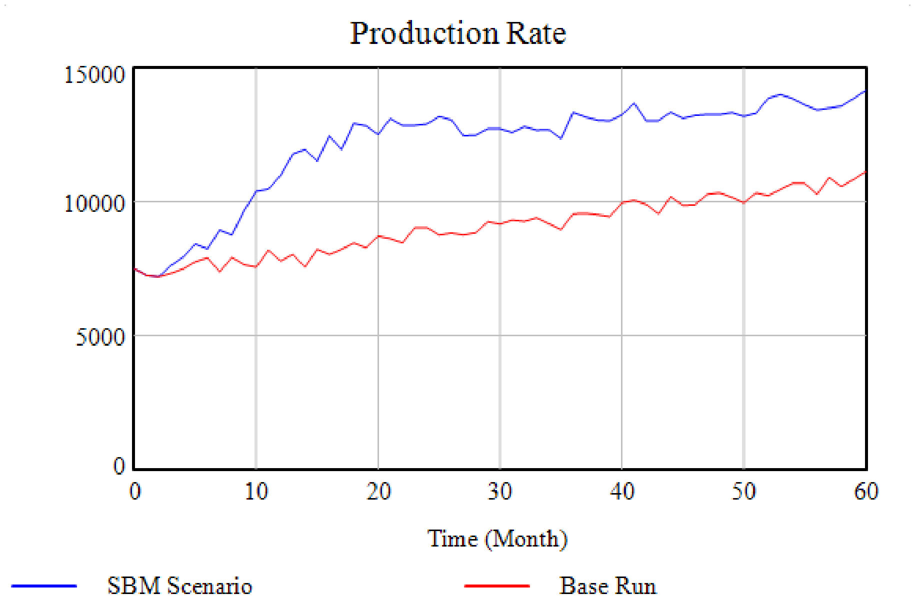

Figure 10. Production rate

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The long-term nature of the investment in the transformation to a sustainable business model is evident in Figure 11. The financial resources decline in the process of creating collection capacity and establishing the recycling and reuse capacity in the production line. The money that is saved by using recycled material and used parts and the money earned by the higher demands caused by improved brand compensates for this decline, and eventually, there is a breakeven point at the 55th month; after that, the company financially benefits from transforming to a sustainable business model.

Figure 11. Financial resources

7. Discussion

This section of the article develops some discussions around the issues raised during the research and offers some policy recommendations that might be helpful at different levels.

First, as mentioned in the previous section, the decision to move towards a sustainable business model is a tough decision regarding the risks, the most important of which is the financial risk coming mostly from the initial investment needed to establish production lines and reorganize the factory. According to the simulation results based on the data from the case, the initial investment for establishing and the changes in the production line, together with other costs, are compensated in 55 months from the savings of material and parts. There are also other advantages in this plan, for instance, the improvement of the company's green image; however, the benefits of such advantages are not guaranteed and may take a long time. Most companies withdraw from ambitious plans of changing their business plan when facing the costs of transformation. It is very appropriate at this point for the government incentives to enter the game when companies are making their initial investments in changing their business model. By looking at the dynamic of the model in Figure 6, you will find out that everything depends on the financial resources of the plan, and if the government takes the lead in investing in the sustainable business model transformation, it could start the engine of this transformation, and then different parts of the system could run in their sequence. If the government pays for the initial investment in long-term loans, more companies might be interested in getting their shoes muddy in the transformation process.

Second, the company under study uses the parts and the used products from its customers and then maintains the whole recycling and reuse process in the manufacturing factory. The model has no supply chain between the recycling and reuse processes and the production processes. In other words, in the model, the recycling and reuse processes are integrated into the production processes. This is aberrant because gathering, preparation, and production of reusable parts and recycled raw material are generally done in separate supply chains in separate places and perhaps by separate vendors. The case under study is in Iran, where no reliable local recycling and reuse supply chain is available. Integrating recycling and reuse in the production processes in this company is a result of using the opportunity to access the customers' recyclable and reusable waste. This could be a good example for plastic manufacturers in countries where a reliable recycling supply chain is absent and for those with access to their customers' waste and used products. To persuade the customers to get involved in the plan, the manufacturer could offer incentives with a mutual benefit like renewal plans for the products. One policy recommendation that could be implied from this issue is to build an effective plastic recycling life cycle near cities and industrial areas. It is best to collect, refine, and reproduce the raw materials in separate factories because they have their supply chains, processes, and requirements. In some countries, each of these steps is handled by a separate factory that is specialized in one of these steps. In this way, the whole process would be more efficient, and the general quality of the output material would be expectedly higher.

Third, one of the key factors in our model is the quality of products. The quality of products is affected by many factors depending on the product's type and process. A simple way of expressing this issue is that by adding second-hand material to the input of the production system, the product quality declines. It is the job of the factory's quality management system to measure, control and manage the quality of the product. The quality management system also defines the product quality and finds out what factors affect the quality of the product by the product design, usage, and other factors and expectations. However, we should consider the quality issues in our model because the input material is key in maintaining the quality of the product. A concern of the quality management system is to find the correlation between the ratio of recycled material to raw material and the quality of the product.

Nevertheless, some important practical concerns here might complicate the relations between these factors. First, the quality of the input material is not the only factor that affects the product quality. There are always ways to increase the quality of the final product by maintaining those other factors without changing the input materials. These practical concerns are outside the scope of this research; however, to name a few, we should refer to maintaining the production process with the ratio of recycled material. Another inexpensive way to compensate for the quality decline is to add some chemicals to the recycled material. It is a long list that changes for each product and material type. We had to omit such concerns from our model to make it simple and universal.

Finally, the model put forward by this research is a simplified version of the real model; however, it is detailed enough to convey the complexity of business decision-making in the real world. We had to limit the level details on the proposed model to make it applicable to other cases of the same nature. Although the number of variables in the case might not be the same as in a real problem, there is at least one variable with the same characteristics as in a detailed version of any real problem of this kind.

8. Conclusion

In this paper, we used the System Dynamics Modelling approach as a decision tool for evaluating decisions regarding the changes made to a plastics manufacturing company's business model to make it more sustainable.

According to the literature study, there are several ways to transform the business model into a sustainable one. Of course, for every industry, some options work better. In the case under study, there was access to the customers' waste and used inventory; therefore, the manufacturing company integrated the recycling and reuse processes with production processes.

The modeling helps make a better understanding of the business model transformation, and with the help of simulation results, the company's decision-makers can have an outlook on the strategic factors that play a role in the decision-making process. In addition, we offered some recommendations that could help the business owners transform their business models.

We recommend that future research measure the environmental factors in the model. Factors like changes in the price of raw materials, changes in the public policies regarding the use of first-hand materials, and changes in the tax laws are not under focus in our model, and playing them could make a more accurate model.

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Simulating Crowd Behavior Using Artificial Potential Fields: An Agent-Based Simulation Approach

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ABSTRACT

This paper presents an associate agent-based model (ABM) of the rebellions where protesters and mobs move in a crowd and try to reach valuable sites while cops settled in front of sites to safeguard them and use obstacles to disperse them. This paper aims to show how people during a protest decide and steer to get their target, such as valuable buildings. To simulate the protest and entities, we employ agent-based modeling, which provides a flexible tool for assessing scenarios. Our paper uses steering behavior techniques to simulate the higher cognitive process of rebellions and police at the microscopic level. It considers the special characteristics of protesters' behavior, like avoiding obstacle collision relating to perceived hardship and grievance. The artificial potential field is used to show the movement of people. The projected model consists of 4 forms of agents; policemen, protesters, mobs, and facilities that give an acceptable framework for future studies.

Keywords

Behavioral Operations Research, Simulation, Artificial Potential Field, Crowd Steering Behavior, Agent-Based Modeling.

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1. Introduction

Civil violence, dispensed as a signal of defiance against a central authority or between opposing teams, has been utilized in the context of recent society to explain associated actions of violation. That's manifested in numerous forms and categorized according to the character, the severity of the conflict, and conjointly degree of involvement (Quek et al., 2006). These vary from little-scale riots and protest to giant-scale revolutions like ethnic wars. Researchers are seeking to interpret the most reasons and effects from numerous views. In most cases, riots occur once giant, hostile teams of individuals gather and perform property destruction and often fight with police. United Nations agencies are deployed to manage the gang. Within social conflict theory (McLellan, 1971), many researchers take into account unrest because of the results of instability in the socio-economic atmosphere (Situngkir, 2004). With accordance to Pires and Crooks (2017), they can be as results of a spread of social and political grievances, like inequality (Jackman, 2002), lack of resources (Auyero & Moran, 2007), or the unfair treatment of civilians by authorities (Stark, 1972). We can notice studies concerning riots at intervals in many disciplines, as well as social science (e.g., Tucker et al., 1999), military operations (McKenzie et al., 2004), and physics (Pabjan & Pekalski, 2007).

Crowd Control is some actions that apply force to prevent or disperse an outsized, hostile group. Organization to control crowds includes team members, formations, and instrumentation. Generally dispersing a riot involves the employment, or threat to use, violence. Studying the great motion of individuals dynamics affects a large variety of applications together with behavioral sciences, escape designing, stampedes, event organization, and controlling crowds (Kirkland & Maciejewski, 2003).

Police operations to manage crowds may be a complicated, culturally specific method (Wise & Cheng, 2016), and officers have to have several decussate responsibilities. Programs for managing riots are with success used with a spread of samples as well as community members, school students, prisoners, internal organ patients, abusive spouses, and showing emotion disturbed or disabled young people (Brondolo et al., 1994; Friedman et al., 1984; Gerlock, 1997; Kellner & Bry, 1999; Holbrook, 1997; Miranda & Presentacion, 2000; Brondolo et al., 2003, Makowsky & rubin, 2013; moro, 2016). Conversely, very little attention has been paid to formulating their behavior and additionally deciding, utilizing the abstraction information in creating agent-based models of the protests. It has been argued that this is often a very important, however unnoticed, space, particularly with the rising urban population and youth bulge (NIC, 2012).

The relative analysis literature presents astonishingly few empirical studies of the effectiveness of violence management through knowing offensive behavior against valuable places (Pires & Crooks, 2017). In this case, protesters aim to overcome the building to point out their ability to follow requests.

If we think about riots as agents, the methods they use to manage interactions with the general public will have specific and measurable consequences. Perez and Muir (1996) believe that if community members are dissatisfied with their interactions with the police, they will complain against some officers to the police department's inspection unit. The speed at that civilian's file complaints against enforcement workers is thought to be one marker of a department's effectiveness in coaching, personnel choice, and oversight (Perez & Muir, 1996). As a human being may be a complicated creature, studying lots of citizenries is definitely very sophisticated. Once humans create teams, their interactions become an important part of cluster behavior. In several cases, individuality gets lost, and collective behavior comes on the scene. The linguistics underlying the motion of crowds must be studied extensively to achieve realistic behavior in virtual ones. Therefore, crowd simulation analysis has benefited from the psychology literature (Durupınar, 2010).

From a governmental perspective, business for reconciliation can be valid and intelligible. Several researchers (e.g., Fielding, 2005; Adang et al., 2010) have advocated that investment in peaceful and robust relationships between policemen and citizens will prevent such escalated conflict. Moreover, in several countries, it is acknowledged that the link between police and citizens is ongoing, and cooperation with them is significant and inevitable for police duties (Tyler and Huo, 2002; Skogan, 2005). Different policing strategies, like community-oriented policing (Weisburd and Braga, 2006; Friedmann, 1992), problem-oriented (Goldstein, 1979), and reassurance policing (Fielding and Innes, 2006; Fleming, 2005) advocate making, securing, and keeping appropriate citizen and police relationships (Stronks and Adang, 2015).

Police ought to think about many aspects. Fast mobilization of spare officers to handle the case is significantly important. Delay in reaching the destination might permit the violent crowd to realize such momentum that may be tough to prevent. A spare range of officers should be waiting in reserve at the point of the area. Keep citizens off the streets within the space affected. Do not permit mobs to congregate; keep everybody moving. Innocent bystanders around disorder might be over-excited by their own emotions and acquire concern into members of the mob. Avoid close fighting at the maximum amount possible. Finally, the less force employed in restoring order can cause lasting peace. Any unreasonable act of violence or viciousness by the officers could flip the emotions of the spectators toward the rioters.

We have projected the model with the addition of dissimilar agents. These agents are applied to perform numerous maneuvers for interacting beneath totally different rules. This text focuses on the planning and development of Multi-Agents to check the microscopic behavioral dynamics of civil violence. Agents are sculpturesque from multidisciplinary views, and methods evolve via co-evolution and learning. The agent moves around and attempts to reach the target (e.g., valuable sites) through offensive actions. The projected model results reveal fascinating emergent phenomena and patterns of agent steering behavior and autonomous behavioral development.

The idea is based on Epstein (2002) about civil violence. The results set up micro-macro interconnections among the attributes of warfare and present new insights into the wealthy dynamics that get up from unrest. Epstein (2002) modeled civil violence in a decentralized uprising against a central authority and collective violence between two hostile ethnic groups. An agent-based approach is used and brings out outstanding features of agitator behavior through simple empirical rules and equations of engagement in the microscopic interaction between them. In that model, police and rioters move randomly around, which is considered as one of its limitations. In this paper, we aim to introduce agent movement toward a specific target (e.g., valuable sites) by applying artificial potential field. We are interested in the modeling of human agents belonging to an explicit group in which the members are in a well-defined formation. Specifically, we have used the steering behaviors framework to develop a simple model of civil violence for police as guardians of valuable places.

The organization of this paper is as follows: section 2 presents a short review of existing works in the literature. Section 3 introduces the model specifications. Section 4 presents a brief explanation of agent-based simulation, and in section 5, our proposed framework with computational agent-based simulation is presented, while section 6 concludes the paper with an overview and some suggestions for future works.

2. Previous studies

Different types of empirical simulations have been carried out over the years to model complex dynamic systems in different disciplines (Goh et al., 2006). The simulation of human behavior from the earliest days of computer graphics research has been studied. The first thing is focusing on animal behavior, but a lot of recent work has been done about human behavior. In addition, techniques are proposed to simulate a group of individuals as a single entity and consider each individual in the population separately. Reynolds (1987) carried out the first work, which popularized the whole field. He introduced a simulation of a herd of birds. The main point he introduced was that each bird is treated individually. A combination of every bird that follows a set of standard rules leads to flocking behavior for the entire group. Each bird had three main bases: going to other birds trying to match the speed of the boat around, and preventing collisions (Rymill & Dodgson, 2005).

Moreover, the MANA model (Yiu et al., 2002) proposed an extension to Epstein's model by introducing specific movement strategies aimed at correcting the completely randomized movement of factors. Also, Situngkir (2004) utilized empirical formulation for modeling the phenomenon of massive conflict by invoking its analogy with the macro-micro link in Sociological Theory.

Bandini et al. (2004) used cellular automata and autonomous agents to model the pedestrian population based on the so-called cellular agent approach. The simulation of individual aspects, such as selective ones, was modeled using the ABM approach, while physical aspects like information transfer, understanding, and movement are solved using local rules based on cellular automata. This combination provides a model which can be used for analyzing back-and-forth scenarios. It involves complex abilities to reach an agreement among the agents and to join and leave the groups of delegates who have agreed. A cellular agent approach to simulating pedestrians is used in a subway station scenario (Bandini et al. 2009) and pedestrians visiting a museum (Bandini et al. 2004).

Goh et al. (2006) improved Epstein's model of civic unrest between two groups. Agents such as the Epstein model can be silenced, activated, or imprisoned, and active opposition agents can murder the agent. Their work suggests describing population agents consist of some improvement in relation to Epstein's: 1) the tendency of revolting is expressed in terms of two attributes, grievance G and greed G_r and a time factor T_f weighting them 2) the steering is with accordance to specified strategies, which are improved by evolutionary learning; 3) the net risk modeling consists of a deterrence term including the maximum prison term. Their model offers a more realistic description of Epstein's movements and operating jails, including the effects of learning and memory on the characteristics of the agents.

Ronald et al. (2007) model pedestrian crowds using a BDI agent approach. They apply this approach to simulate audience behavior at the stadium, where visitors' attractions are available.

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Pedestrians are autonomous agents with a lot of information about the environment and their own, such as attractive locations, the impact of their activities on the environment, and the things that need to be done on failures. Also, agents can communicate directly with each other.

Ballinas-Hernández et al. (2011) define a model of nomadic populations using ideas from the field of the kinetic theory of living systems, besides computational agents. Their work supports quantitative characterization of the function of agents supports a neglected issue in ABM models through kinetic parameters. Flow and activity algebra graphs for both groups, continuous homogeneous passersby, and heterogeneous pedestrian groups are presented regarding their desire to achieve their goals.

Kim and Hanneman (2011) introduced a model of employee protest that supported Epstein's model that comes with 2 necessary factors best known from psychological science research: 1) the grievance is defined in terms of relative deprivation (RD theory ensuing from wage inequality) and 2) cluster identity effects. The advantages of the model square measure the introduction of sound principles from psychological science and grievance modeling, risk aversion, and peer effects. However, the model additionally shares necessary limitations (homogeneity of the surroundings, Impractical Movement of the agents, etc.).

Davies et al. (2013) introduced a model for the London riots in 2011 based on three elements: 1) a contagion model for participation decision making; 2) a model for choosing the site and a model to show the interaction between rioters and police. Their model tried to understand the patterns of riot behavior besides the allocation of officers to neutralize similar events. The model uses statistical descriptions and simulation and incorporates data on deprivation based on official reports. The environment includes a list of residential sites and j retail shops in London where the riots occurred. In step: 1) one agent in the residential area decides to participate riot based on its deprivation and function of the attractiveness to riot, which is a function of the distance between its retail site and residential area, the floor space, and the deterrence expected at j; 2) if the agent decides to riot, it chooses the retail area to go, based on his utility that takes into account the distance between two places, (the deterrence depends on the expected number of officers at the chosen rioting site) and 3) rioter interacts with the officers and maybe prisoned with probability P (Lemos et al.,2013).

Niemann et al. (2021) studied the behavior of the ABM process on a long-time scale. They showed that, under certain conditions, the transfer operator approach allows us to bridge the gap between the path-wise results for large populations on finite timescales, i.e., the SDE limit model, and approaches built to study dynamical behavior on long time scales like large deviation theory. They provided a rigorous analysis of rare events, including the associated asymptotic rates on timescales that scale exponentially with the population size. They demonstrated that it is possible to reveal metastable structures and timescales of rare events of the ABM process by finite-length trajectories of the SDE process for large enough populations.

In this work, a complete specification of the goals and actions of the system entities is needed to modify the execution of possible schedules; conjointly, we tend to propose the choice creating of police and rebellions in the case of an attack on a special site that guardians should protect.

3. Advantages of ABM in riot studies

Riots occur when the social context leads to significant levels of grievance in a large proportion of the population and raises the level of internal conflict within the society. People become aware of the riot through several sources, and the decision to join it can be contagious. In the early stage of assembly, the crowd may behave peacefully, or part of them may decide to engage in a violent confrontation with officers. Depending on the depth of the social conflict and the grievance level, the riot may last more or repeat cyclically, which in turn changes the social context (Lemos et al., 2013).

Given the challenges imposed by the crowds, Modeling and Simulation techniques, in particular, Agent-Based modeling (ABM), are widely used to study the complex interactions of individual people in a crowd beside the emergence of group behavior Bonabeau, 2002; Laclavík et al. 2012; Hu et al., 2012). Agent-based modeling enables to study of the consequences of actions that protesters and officers may carry out in protest management (Hu et al., 2012).

We have two components of bounded rationality: bounded information and bounded computing power. Global information and infinite computational power do not exist for agents, and they use local information to make use of simple rules (Epstein, 1999).

The ABM is especially powerful in representing spatially distributed systems of heterogeneous autonomous actors with bounded information and computing capacity who interact locally.

Individuals are modeled as intelligent agents with specific attributes and can make a decision independently based on decision rules. Modeling the decision-making process of humans is important for designing the decision rules (park et al., 2015). The explanation mentioned above shows that we should employ agent-based simulation to know the nature of human behavior in civil violence.

4. The proposed framework

In an agent-based model, an agent represents any unit that can behave like a person or vehicle that can exist in the same simulation. The surroundings may include spatial spaces such as streets or social spaces that define relationships between agents, influence and constrain their behaviors, and are known as the simulation's environment (wise and Cheng, 2016). In the agent-based computational model presented in this paper, four types of agents interact; protesters, mobs, policemen, and facilities. Protesters are members of a population who act against a central authority and decide whether or not to rebel against the government based on their degree of economic and political grievance shown by aggression (park et al., 2015). It is an agent whose aggression level is normal by default. It can be influenced by either a mob agent or a guardian; when it is influenced by a nearby mob, its aggression level increases and follows the mob, damaging properties together. When nearby police influence it, its aggression level goes down from normal to good, making it non-violent. Also, Mobs are the other kind of members with a higher degree of grievance. It is an agent whose aggression level is always high and who tends to damage properties such as breaking store-front windows and burning cars. It influences nearby protest agents to increase their aggression level. It has a behavior of going to its destination, such as valuable sites. The people must not pass critical areas, so policemen arrest them as soon as they enter the alert area.

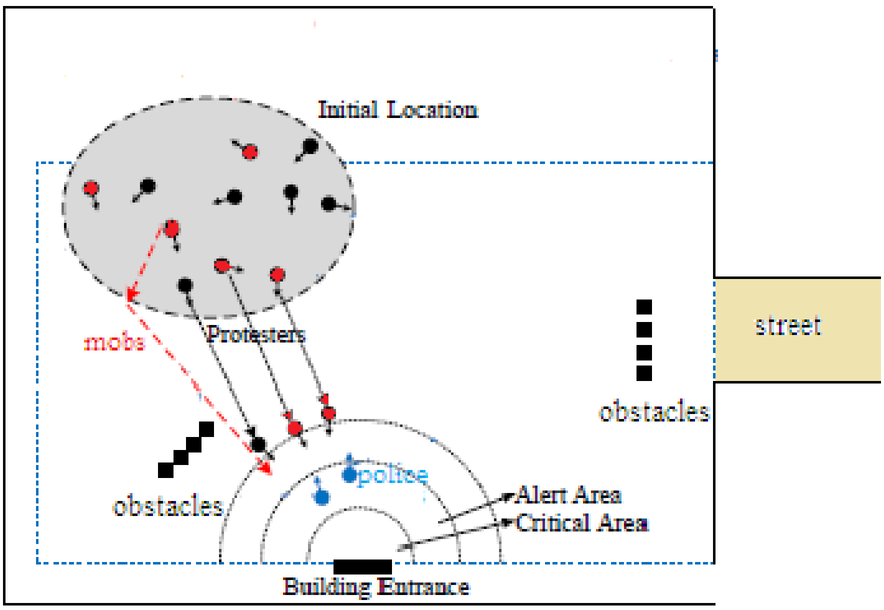

Figure 1. Depicted scenario

Policemen are the forces belonging to the central authority who should suppress any rebellion by showing off their power by locating in appropriate situations (for surpassing protesters) and arresting mobs. Facilities are places such as state-building, which must be protected from attack.

Figure 2 shows a plan of the procedures that lead to social changes. As per this, a tactile boost causes a conduct response that relies upon the individual points and is looked over many social choices with the target of utility expansion. Be that as it may since an operator is utilized to the circumstances he is regularly stood up to, the response is typically rather programmed and controlled by his experience of which one will be the best (Helbing and Molnar, 1998).

We simplify the thought process to consider a single choice, whereby an agent must make a single decision by considering a series of options. Protesters and mobs wander and try to close to facility agents for conquering. According to Zhong (2014), whenever an agent receives a stimulus, the mental process is broken down further into a sensing phase, an assessment phase, and a decision phase.

Sensing phase: In this phase, the decision-maker perceives environment features and discovers alternative options. For example, when people are going toward targets, the perceived information can be the distance to each target, driving, and repulsive factors (attraction of target and presence of policemen). Different targets are alternative options for the same decision (i.e., which target to choose).

Assessment phase: The subsequent stage is to evaluate every variation alternative. This stage is the most significant and complex part of the basic leadership process. Whether an elective alternative is great or not is subject to the particular setting and different physical, social and mental variables. We can respect the way toward surveying an elective alternative A_i as a capacity that maps apparent highlights to reward esteem.

Decision phase: Given those mentioned above, this stage essentially picks the best choice, for example, the alternative with the biggest reward. In view of the above presumptions of the basic leadership process, structuring choice standards for a specialist-based group model is a procedure of finding the relating prize capacities (Zhong, 2014), which could be different in various cases.

After making the decision, a reaction will occur. It is, therefore, possible to put the rules of pedestrian behavior into an equation of motion.

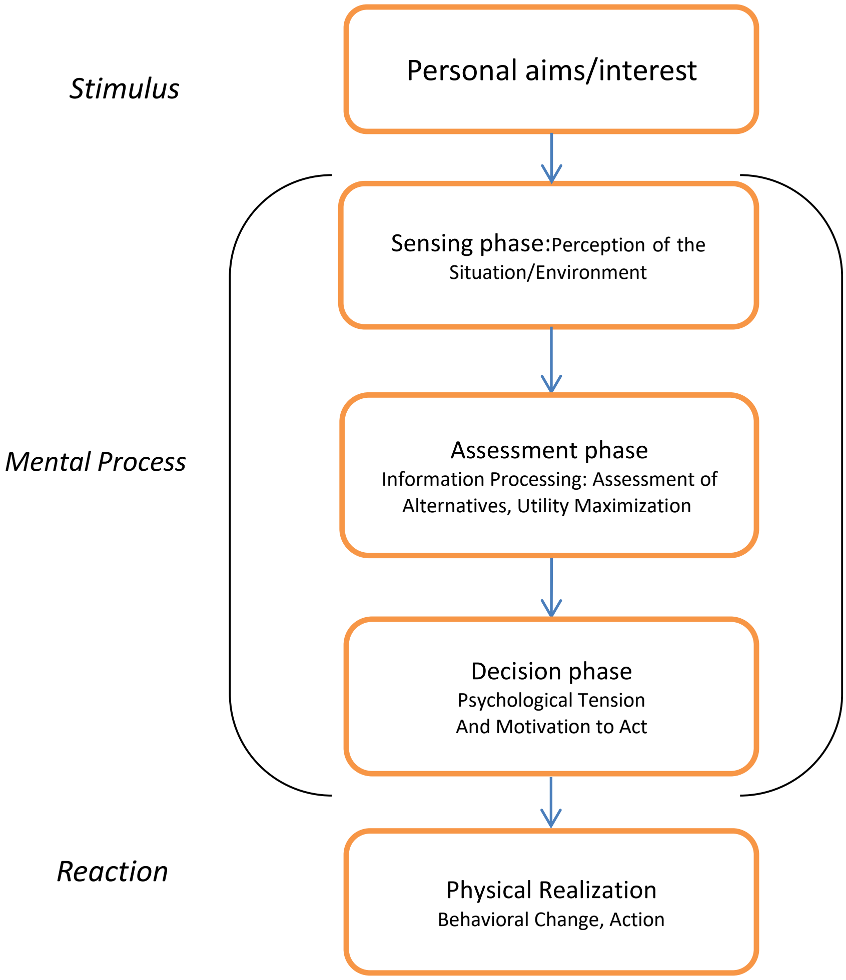

Figure 2. Schematic representation of processes leading to behavioral change

In the following, we propose the computational behavior of agents during a riot to reach target sites.

4.1. Protests and mobs

The features of each agent are described in detail, beginning with the citizen agents (protests and mobs) specification because their specifications are similar, excluding parameters. As in Epstein (2002), social grievance shows the motivation that potentially leads protesters to revolt; for each protester *i,* the grievance is assumed to be the product of an index of economic hardship. H is the agent's perceived hardship like physical or economic privation, which is exogenous in the interval (0-1) and a measure of government illegitimacy, defined as $1 - L$, where L is a parameter measuring the legitimacy of the central authority which is exogenous and is equal across agents, and in the runs discussed below, will be varied over its arbitrarily defined range of 0 to 1 (Epstein, 2002). So the grievance will be:

$$G(y_i) = (1 - l)H(y_i) \quad (1)$$

According to Kim and Hanneman (2011), H(yi) as perceived hardship is an ego's wage minus the local average within a certain radius (i.e., 6 patches in our experiment).

$$H(Y)_i = W_i - aveW_j \qquad j = 1, \dots n \quad (2)$$

Where W_i is the wage of protest i and W_j is the wage of his neighbors in radius. Relative deprivation is required to arrive at its greatest when the populace is similarly isolated into a gathering of rich individuals and a gathering of exceptionally destitute individuals. Notwithstanding, we expect that sentiments of relative hardship come from nearby examinations regarding reference bunch inside which an individual limits her desires. On the other hand, the cost of participating in a riot is defined as the product of the estimated probability of being arrested A_i and the opportunity cost of joining a revolt J:

$$N(y_i) = A_i J(y_i) \quad (3)$$

In fact, each protester and mob gauges the likelihood of being captured before effectively joining disobedience. This assessed likelihood is characterized as in Epstein (2002): it is an expanding capacity of the proportion of cops to officially defiant operators inside the hordes and dissenter's vision range (Moro, 2016).

$$arrest\_prob_i = 1 - \exp\left[-k\left(\frac{C}{A}\right)\right] \quad (4)$$

Where C is the number of cops in radius, A is the number of mobs within the protest's vision, and k would be exogenous. The vision, a circular neighborhood with the center in the protest's position and a radius equal to v, represents the lattice positions probed by the protests.

The main rule for protesters to become active mob is a simple cost-benefit as follow:

If G(yi) - RAi >Tr then be mob. (5)

Where RA_i is the risk aversion of protester i and Tr is a threshold defined by the researcher. the RA_i is formulated as follows:

$$RA_i = Nr - arrest\text{-}prob \quad (6)$$

Where Nr is tolerance specific for each protest and randomly distributed. The one in the past recipe makes unequivocal that, before envisioning in a mob, a challenge will consider himself

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a functioning specialist; along these lines, the proportion is in every case all around characterized. By and by, the floor administrator is connected to the proportion of police officers to insubordination operators, as in Wilensky's (2003) version of Epstein's model. But the function mentioned above is appropriate for open space. During guardianship of important sites, when the police are 'outnumbered' at a site, the circumstance is viewed as wild, and the police can't make any captures without the expansion of 'reinforcement' (and in this manner, the likelihood is 0). Going to prevention as unpleasant power, we recommend that the essential check by which an individual surveys whether the circumstance at a site is helpful for defiance is the likelihood of capture, dictated by the general quantities of dissenters, crowds, and police: an apparent low shot of catch supports investment.

In Epstein (2002) work, agents move around randomly. But we assume that they wander wisely and under some forces. They wander around and are attracted to get their target (facility agent), evading collision with others and escaping from policemen.

This paper focuses on the microscopic modeling of people's movement on the operational level, where a model generally has to take care of the following two tasks: 1) each pedestrian wants to walk with an individual desired speed to target, while 2) keeps a certain distance from obstacles.

According to Helbing and Molnar (1998) agent wants to reach a certain destination $\overrightarrow{r_1^0}$ as comfortable as possible. He normally takes a way without detours, i.e., the shortest possible way.

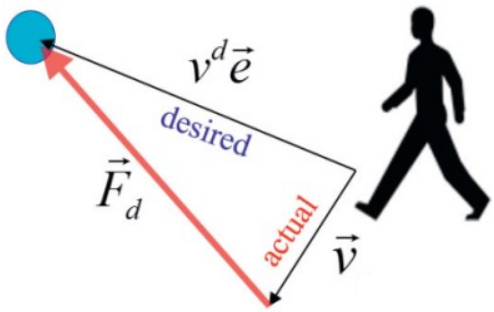

Figure 3. Driving force of an agent

To model moving rebellions, Artificial potential fields are applied. The fundamental building block of potential fields is the action vector, which corresponds roughly to the speed and orientation of a moving robot. Each behavior outputs the desired output vector. For example, consider a *Seek-Goal* behavior assigned the task of making the robot head toward an identified goal. The output of the *Seek-Goal* behavior is a vector that points the robot toward the goal. Let (x_G, y_G) denote the position of the goal. Let r denote the radius of the goal. Let v = [x, y] ^{T} denote the (x, y) position of the agent. So the distance of agent to goal is:

$$d = \sqrt{(x_G - x)^2 + (y - y_g)^2} \quad (7)$$

Also, the angle between the agent and the goal is:

$$\theta = tan^{-1}(\frac{y_g - y}{x_g - x}) \quad (8)$$

If an agent's motion is not disturbed, he will walk in the desired direction $\vec{r}_i^k$ with a certain desired speed v_i^0. On the other hand, It gets interesting when, in addition to the *Seek-Goal* behavior, we have other behaviors such as the *Avoid-Obstacle* behavior.

Let (x_O, y_O) denote the position of the obstacle. Let r denote the radius of the obstacle. Let v = [x, y] ^{T} denote the (x, y) position of the agent. So the distance of the agent to the obstacle is:

$$d = \sqrt{(x_o - x)^2 + (y - y_o)^2} \quad (9)$$

Also, the angle between the agent and the goal is:

$$\theta = tan^{-1}(\frac{y_o - y}{x_o - x}) \quad (10)$$

Within the obstacle, the repulsive potential field is infinite and points out from the center of the obstacle.

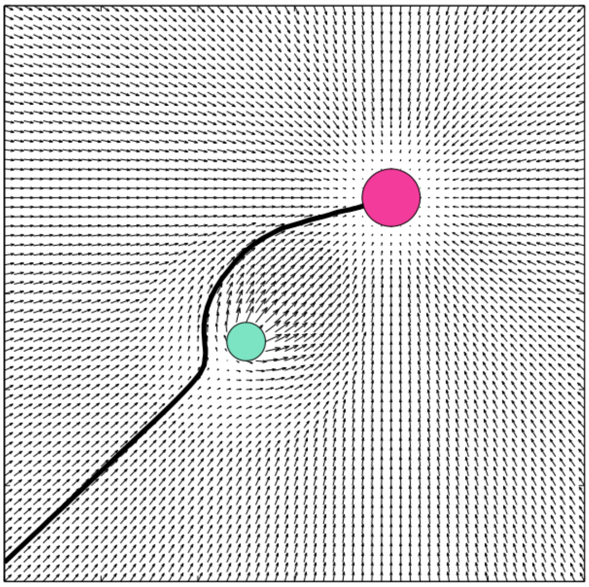

Figure 4. robot behavior when there is a goal (Goodrich, 2000)

4.2. Policemen and facilities

If intelligence indicates the possibility of violence, a Police show of force when the strike begins may prove to be a good psychological deterrent. 1) Only sufficient Troopers should remain on the scene, however, to properly handle the existing problem. Additional personnel should be in a nearby location and held in reserve. We assume that policemen are guardians of buildings to prevent rioters from closing them. Thus, they must not go far from sites and, coincidently, should arrest rioters (protesters and mob) who rich the alert area. The policemen are a lot less complex than imminent rebellions. Their properties are as follows: the cop vision is the number of cross-section positions (north, south, east, and west of the cop's present position) that the cop can examine. It is exogenous and equivalent crosswise over police officers. The police officers' vision need not rise to the specialists; however, it will normally be little with respect to the grid size and police vision is in the neighborhood. Like the other agents, the policemen follow one simple behavior rule: *Inspect around and arrest a protester or mob agent in an alert area*.

As mentioned above, mobs and protesters aim to get facility agents and escape from policemen, while policemen are attracted to arresting agents if they violate the alert area.

As the model focuses on protecting valuable sites, policemen are not allowed to go further. Thus, the movement domain of police agents is in the alert area. Showing off power firstly and arresting closer rioters are the main tactics. The jail terms for arrested agents are exogenous and set by the user. In particular, the client chooses an incentive for the most extreme prison term. At that point, any captured operator is appointed a correctional facility term drawn arbitrarily from $U(0,J^{max})$. J^{max} will affect the dynamics by removing agents from circulation for various durations (Epstein, 2002).

The facility agent is a valuable site that is the target of rebellions to be destroyed. This kind of agent is passive and fixed. The main specification is the degree of importance to be protected (e.g., government site or gasoline station).

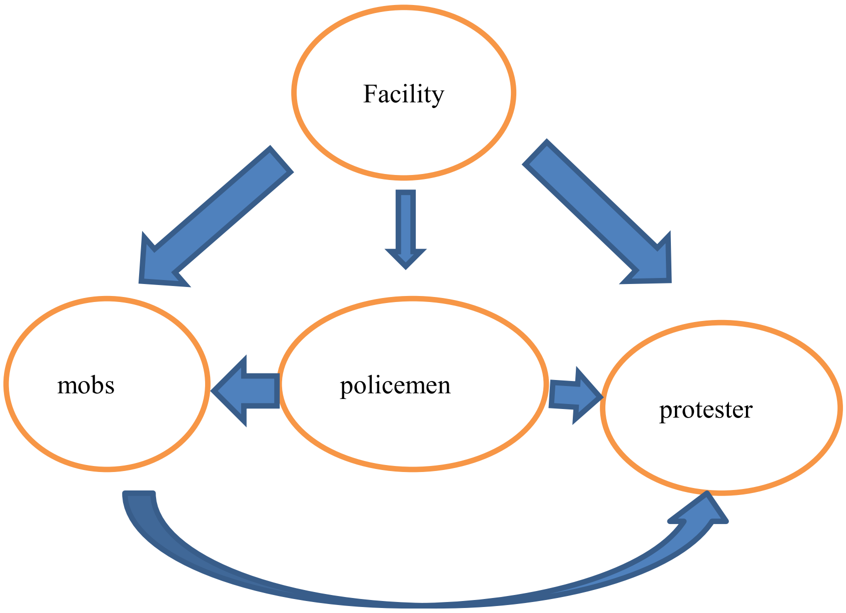

Figure 5. the interaction among agents

5. Results

To implement simulation, we use NetLogo software introduced by Wilensky (2003). Before running, the ODD protocol was provided. Protesters without leaders are located on a 40 x 40. They realize just what is happening in their prompt environment. In our model, an operator watches the conduct of neighboring colleagues whose good ways from her are not exactly or equivalent to 5 (vision). The number of protests differs in 50, 67, and 84. The grid is also occupied by cops agents who arrest active protesters and mobs. As in Epstein (2002), 17 cops are randomly arranged in front of buildings to arrest protesters in the alert area.

We also used the approach mentioned above to localized relative deprivation, which would define it as the difference between each agent's wage and that of the most highly paid agent in the neighborhood. The wage of protesters is distributed in a normal and random way among all of them, $W \sim N(0.5, 0.167^2)$. Figure 6 depicts the wage histogram.

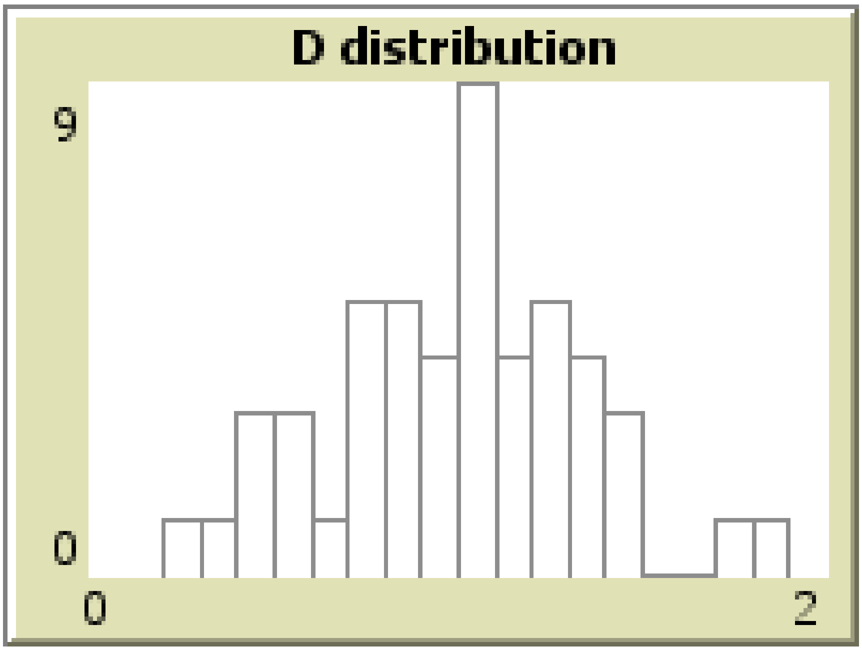

Figure 6 histogram of the initial wage distribution

Agents in our model independently assess the risk. The Nr (tolerance for each protest) as an exogenous variable for calculating deterrence is distributed normally and randomly Nr~ N (0.5, 0.167^2). Following Wilensky (2003), k = 2.3 is a constant set in 'startup' to ensure a reasonable value when there is only one cop and one agent within a certain vision. Also, we run the model in 12 scenarios based on changing legitimacy (0.81 and 0.69) and the number of rebellions (50, 67, and 84) and using obstacles to ban rebellions from closing sites. Table 1 shows the parameters and variables for running the simulation.

Table 1. model parameters for initialization

quantity	Variable or parameter
2.3	K
0.5	lambda
0.4	Alfa

As shown in table 2, The grievance distribution in our model differs somewhat from that of Epstein (2002). In the first scenario (without obstacle), with a moderate number of rebellions (N = 67) and higher legitimacy, the average grievance in our model (0.0254) is a little less than others. Also, at a moderate number of rebellions (N = 67) and lower legitimacy, the average grievance in our model (0.0401) is higher than others. But on the other hand, in the second scenario (without obstacle), grievance, when N = 67 and legitimacy = 0.81, is a little more than others, while when legitimacy = 0.69, the grievance decreases.

Table 2. Averages of Grievance and risk aversion in Epstein (2002) and Our Model (without obstacle)

legitimacy	Number of rebellions	Our work (without obstacle)		Our work (with obstacles)	
		Grievance	Risk aversion	Grievance	Risk aversion
0.81	50	0.0255	0.0409	0.0239	0.0204
0.81	67	0.0254	0.0479	0.0250	0.0300
0.81	84	0.0255	0.0583	0.0249	0.0397
0.69	50	0.0401	0.0535	0.0250	0.0300
0.69	67	0.0416	0.0681	0.0248	0.0397
0.69	84	0.0409	0.0791	0.0395	0.0239

As shown in table 2, the risk aversion increases when the number of rebellions increases. Whether a worker protests or not is contingent on both grievance and a rational calculation of the net risk. The net risk, in turn, is determined by an exogenously fixed individual level of risk-aversion and the estimated probability of being arrested. In our model, risk aversion is equal to deterrence multiplied by Estimated Arrest Probability (P), as is in Epstein's model. But, Nr ~ N (0.5, 0.167^2), instead of Nr ~ U (0,1) in his model. Following Kim and Hanneman (2011), we assume that most rebellions have degrees of deterrence close to the mean in the population, with a small number of outliers above or below the mean.

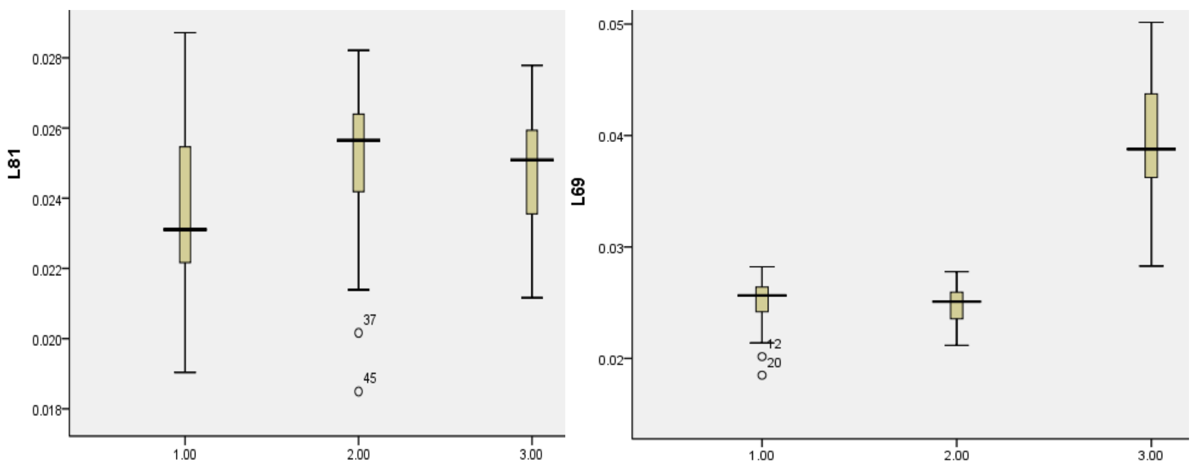

Figure 7. box plots of Grievance with obstacles (L= 0.69 and 0.81)

Box plot summary represents the distributions of grievance in different levels of legitimacy and the number of cops in two main scenarios. The plots depict that the distribution of grievance how varies in scenarios.

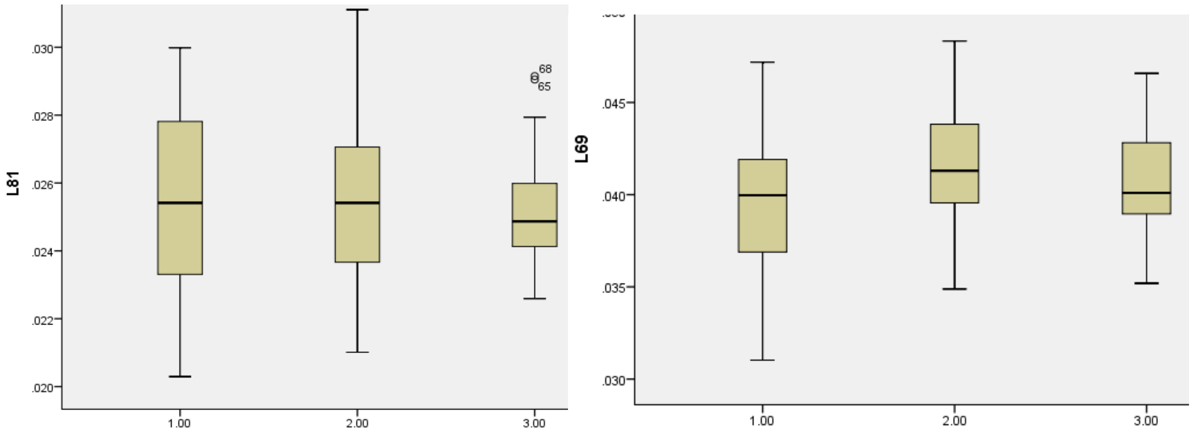

Figure 8. box plots of Grievance without obstacle (L= 0.69 and 0.81)

Comparing these, it is apparent that sensitivity to deprivation is an important factor determining grievance for the conditions analyzed in the experiment.

At the beginning of each round of the simulation, we allow rebellions that are not arrested for moving toward the target considering colliding obstacles. Workers then become active if the difference between their grievance and risk aversion falls above a fixed threshold (0.1, as in Epstein's model). Figure 8 shows the number of protesters and mobs in a repetition of both scenarios.

Table 3 shows the analytical result of simulation when police use obstacles as a tactic for crowd control our let them close to valuable sites without obstacles. As depicted before, the artificial data is not distributed normally, so we employ nonparametric tests. In order to investigate the significant difference between a grievance and risk aversion among groups, we use the Kruskal-Wallis test.

Table 3. The result of the Kruskal-Wallis test for differences in different crowd size

Legitimacy	Test result	without obstacle		with obstacle	
		Grievance	Risk aversion	Grievance	Risk aversion
0.81	chi- square	0.03	5.64	3.90	35.61
	sig	*0.98*	*0.06*	*0.14*	*0.00*
0.69	chi- square	2.22	21.68	49.57	23.25
	sig	*0.32*	*0.00*	*0.00*	*0.00*

Results show that the difference between rebellions' grievances in different amounts is not significant in the first scenario. But in the second scenario, their grievance of them is significantly different only when the legitimacy of the government is low. It means that in the case of protests in a government with a high level of legitimacy, the police are not proposed to use obstacles to reduce their grievance. On the other hand, the topic of risk aversion differs from grievance. The average risk aversion of people in three group sizes is significantly different in both levels of legitimacy when police use obstacles. But when we concentrate on the legitimacy level, the story becomes different from the first scenario. It shows that group size when the degree of legitimacy of government is higher cannot vary significantly.

Table 4 shows the nonparametric correlation test for investigating the correlation between grievance and risk aversion in all scenarios. The results show that when the police do not use obstacles, there is a significant correlation between risk aversion and grievance, when legitimacy is 0.81 and crowd size is moderate and big, while in the case of legitimacy equals 0.69, only in big crowd size we see a significant correlation.

Table 4. Result of correlation test between risk aversion and grievance

Legitimacy	Number of rebellions	without obstacle		with obstacle	
		coefficient	*sig*	coefficient	*sig*
0.81	50	0.033	*0.81*	0.167	*0.024*
0.81	67	0.280	*0.05*	-0.260	*0.06*
0.81	84	0.035	*0.01*	-0.013	*0.926*
0.69	50	0.153	*0.28*	0.140	*0.32*
0.69	67	0.087	*0.54*	-0.20	*0.88*
0.69	84	0.400	*0.00*	-0.260	*0.06*

On the other side, when police use obstacles, there is no statistically significant correlation in the 0.05 significance level. But if we consider the wider level, it is depicted that when legitimacy is 0.81, the correlation for moderate crowd size is significant. Also, the correlation is proved when legitimacy = 0.69 and the number of protesters is 84.

6. Conclusion

Crowd control poses a great challenge for authorities. We usually expect a well-managed crowd; however, it also usually has a surprise factor. If a disruption happens to the crowd, the disorder will appear and hence cause a mess and casualty accordingly. Realistic simulation of a crowd of people and investigating possible decisions are challenging areas of behavioral operation research. So Crowd simulation has been a significant research topic. Several methods have been proposed for modeling and simulating human behavior, but agent-based modeling is increasingly in use. Epstein (2002) presents an agent-based computational model of civil violence. His remarkable work has been developed in several works by researchers. Random movement is one of its limitations, making it inapplicable to reality. This paper aimed to model the civil violence in attacking valuable sites that guardians must protect. As the target is specific, rebellions try to approach them to destroy, and on the other hand, policemen are missioned to protect them by showing off their competencies, putting obstacles, and finally arresting some rebellions in the case of entering the alert area. Following Epstein (2002), our proposed model regards two kinds of rebellions (mobs and protesters). To simulate crowd steering decision-making, we apply an artificial potential field to explain how protesters and mobs wander to reach the target building. The artificial potential field is modified to the case of guardianship and could be modified and calibrated in future works. We conclude that rioters are willing to reach valuable sites while escaping from colliding obstacles and being arrested by policemen. Eventually, they move under the effect of attractive and repulsive forces. Two forces are manually imposed by police (obstacles and the number of officers) that could differ in situations. As an advantage of our work, researchers and police can simulate the effects of decisions on crowd behavior. Results also show that legitimacy can play an important role in crowd control; the higher government legitimacy, the lower grievance.

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The Role of Wrong Assumptions in Big Policy-Making Mistakes

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A B S T R A C T

Assumptions play a big role in decision-making and policy-making. In other words, assumptions are one of the important components of the mental model that affects the identification, prioritization, and definition of the problem by affecting the type and amount of information received from the problem and also by influencing the model of analysis, analysis, solution identification, and prioritization. They influence decisions and ultimately affect the world around us (Real World). Thus, identifying key assumptions that have led to important decisions helps managers, decision-makers, and policy-makers to make better decisions and policies and correct mistakes. Therefore, this article aims to explain the role of assumptions in decision-making and policy-making by providing several examples of wrong assumptions (misconceptions) that have led to major policy mistakes. These examples are gasoline pricing, steel pricing, and companies' support of science and technology parks. In this article, by examining the numerical database, the policy mistakes were explained, and the governing structure was constructed using the opinion of experts. In the end, a suitable solution to prevent wrong assumptions is presented. The results of the article showed that assumptions by changing the mental model of individuals lead to wrong policies and decisions in various fields. Therefore, to make the right policy and decision, it is necessary to identify and review the assumptions through various means, such as using the opinions of a group of experts and correcting the assumptions.

Keywords

Assumptions, Decision-Making, Policymaking, System Thinking

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1. Introduction

As shown in Figure 1, the overall decision-making and policy-making process begins with issues in the real world around us (Sterman, 2000). In other words, each person in his field of practice in his personal, work, organizational and social life faces issues with different degrees of importance, priority, and urgency. Therefore, information about it is collected to identify and define the problem and identify the factors and causes (information stage) (Forrester, 1980). Then, based on different methods and models, deep analysis and knowledge of the structure causing the problem is done, possible solutions are identified, and the best solution is determined (decision stage). In the next step, by implementing the solution, an attempt is made to improve the problem or eliminate it (action step). At this stage, the person's behaviour changes and leads to a change in the surrounding conditions. Changing circumstances lead to new problems and the repetition of this cycle (Sterman, 2000).

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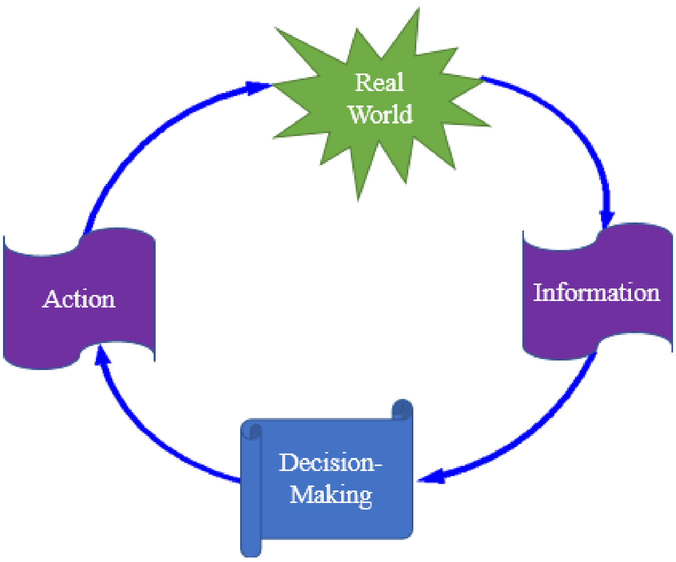

Figure 1. General decision-making and policy-making process Sterman, 2000)

Since assumptions play an important role in decision-making and policy-making (Wang and Hammer, 2015), two questions arise: 1) What is meant by assumptions? And 2) What is the role of assumptions in the decision-making and policy-making process?

To answer the first question, we can say that assumptions are the same axiom or basic principles of each person (Argyris, 1977). Every mental model is based on assumptions about how the real world works (Sterman, 2000). Assumptions are created gradually as a result of education, experience, and interaction with the environment. Assumptions are generally unclear and should be clarified by reflection and reflection. In other words, the individual or organization tends to keep constant within a certain range of these assumptions, goals, and beliefs that are the decision-making framework (Martin and Bidhan, 2012). Assumptions have three characteristics (Argyris, 1977), (Martin and Bidhan, 2012), (Wang and Hammer, 2015):

1- They are formed over time and gradually. Many of these assumptions are shaped by the general decision-making process, whether the decision is right or wrong or whether the person is aware that the decision is right or wrong.

2- Generally, the assumptions are not obvious to the person because, according to case 1, the assumptions are formed gradually. Therefore, in many cases, the person is not aware of the effect of these assumptions on his decisions.

3- A person's or organization's desire to preserve assumptions makes them biased and positive towards it, so they don't see its errors.

Given these three characteristics, and because assumptions are one of the most important components of the mental model, they have an important impact on our lives by influencing our decisions and policies. To answer the second question, as shown in Figure 2, it can be said that the assumptions affect the identification, prioritization, and definition of the problem by the type and amount of information received. At this stage, due to the characteristics of cases 2 and 3, the individual or organization often does not see the effect of these assumptions on their decisions and, ultimately, their problems. In other words, it does not collect information in this area. On the other hand, assumptions affect decision-making by analyzing the model of analysis, identifying the solution and prioritizing it, and ultimately affecting the world around us.

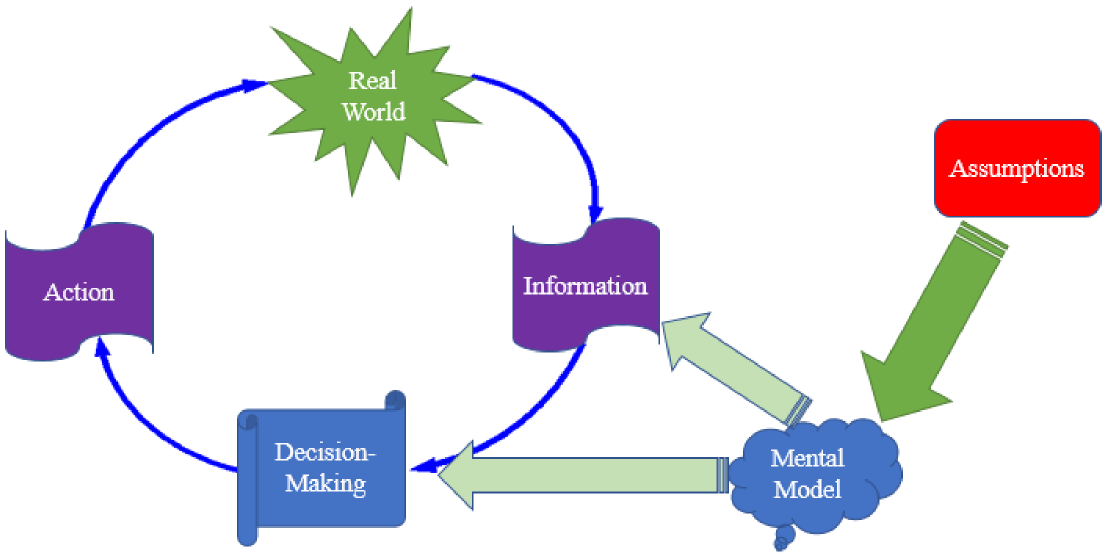

Figure 2. The role of assumptions in the decision-making and policy-making process (Source: Researcher)

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Given the great impact of assumptions on decisions and policies, one can learn good lessons to improve decision-making and policy-making by identifying assumptions in strategic decisions and macro-policies. Therefore, this article seeks to examine the wrong assumptions that have led to wrong decisions and bad conditions in the country. For example, it was stated in an article entitled "Suffering of a wrong assumption" that the wrong assumption of the value of the national currency occurs when we consider the price of the dollar not as a result of the devaluation of the national currency not as its cause (Mashayekhi, 2017). In other words, consider the value of the national currency equal to the price of the dollar. As can be seen from the diagram in Figure 3, based on this wrong assumption, it is assumed that if we reduce the dollar price by injecting dollars from oil revenues, we have increased the value of the national currency. While we may keep the dollar stable or even lower it for a while, the real value of the national currency will fall simultaneously due to rising domestic inflation to global inflation. When domestic inflation is higher than foreign inflation and the real value of the national currency decreases, if the country's officials prevent the rise of foreign currency prices by injecting oil-derived currency into the market with this wrong assumption of the value of the national currency, terrible consequences such as expansion formal and informal imports (smuggling), non-competitive domestic and foreign goods, whose prices increase in relation to foreign goods with high inflation, closure and semi-closure of factories and reduction of investment in production, and finally intensification of domestic inflation is created for the national economy. That will require more currency to import and meet the needs of the country for goods and services. Of course, since the supply of foreign exchange is increasingly impossible, the lack of foreign exchange resources will eventually cause the exchange rate to jump as the country has experienced several currency fluctuations (Figure 4).

If the assumption is correct, the value of the national currency is determined and measured by its purchasing power. If we consider a basket of domestically produced goods and services in terms of the type and quantity of each of the goods and services, some national currency is needed to buy that basket at some point in time. The amount of money needed to buy the basket represents the true power of the national currency. In other words, by expanding production and reducing inflation, the value of the national currency can be maintained, not the nominal stabilization of the dollar (Mashayekhi, 2017).

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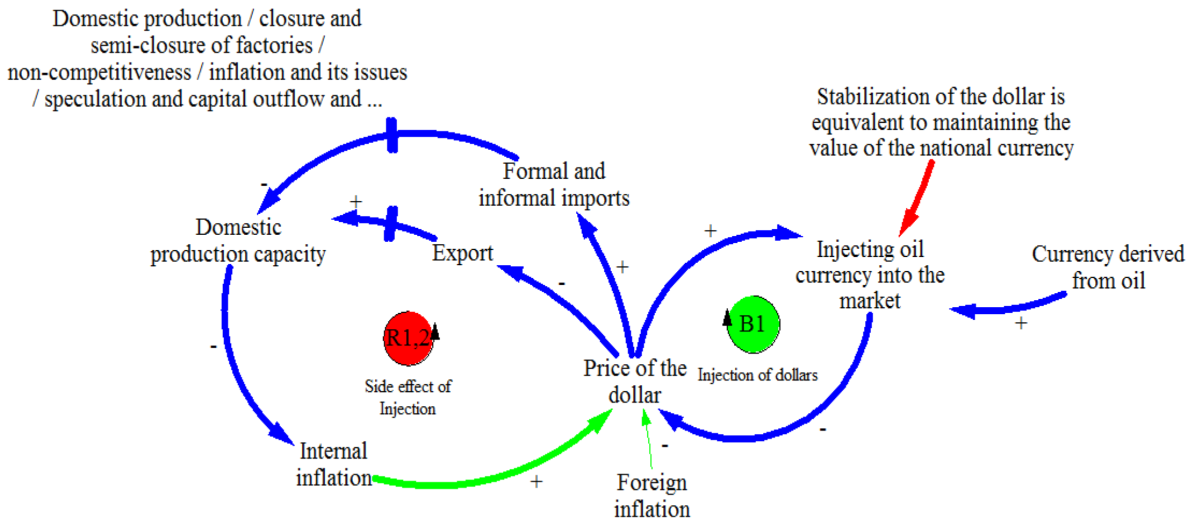

Figure 3: General pattern of the effect of wrong assumptions about the value of the national currency (Source: Researcher)

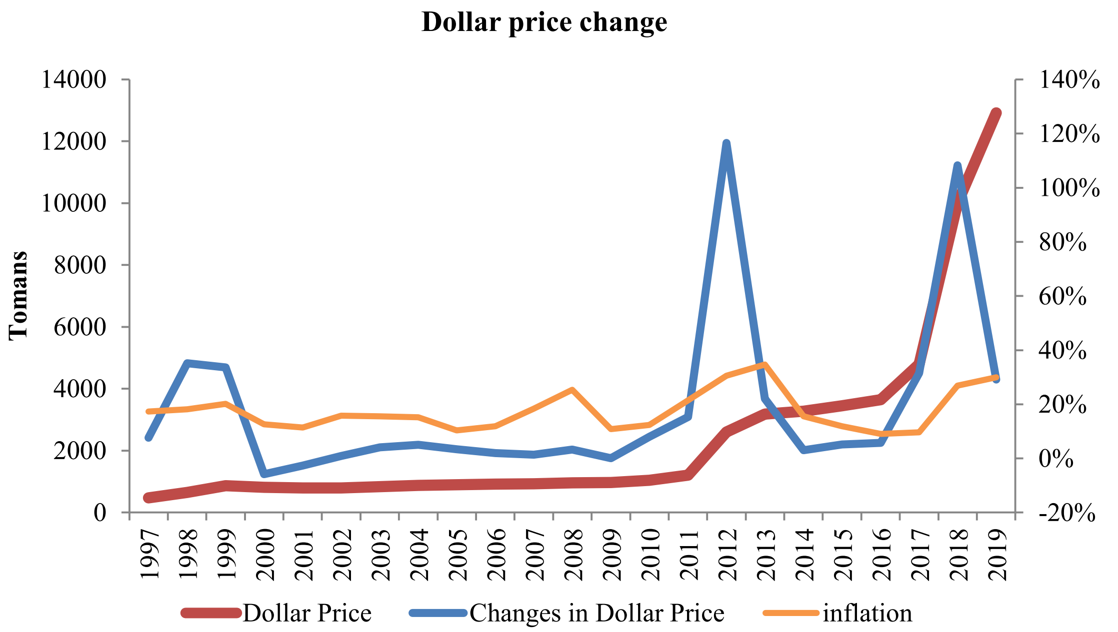

Figure 4: Fluctuations due to the effect of wrong assumptions about the value of the national currency (Source: (Statistical Center of Iran Website,2021))

Given the role of assumptions in decisions and providing an example of big wrong assumptions; Thus, identifying key assumptions that have led to important decisions helps managers, decision-makers, and policy-makers to make better decisions and correct mistakes. Therefore, this article tries to explain the role of assumptions in decision-making by providing several examples of wrong assumptions that have led to major policy mistakes. In this article, the effect of wrong assumptions in decision-making and policy-making is explained by mentioning a few examples in different systems, and then a basic solution to deal with the problem of wrong assumptions is presented.

2. Research methodology

In this section, the research method is explained. This research seeks to answer the first two questions to answer a key question.

The first two questions are: 1) What is meant by wrong assumptions? And 2) What is the role of wrong assumptions in the decision-making and policy-making process? The key question is, what are the examples of the role of wrong assumptions in creating wrong policies (Big Policymaking Mistakes)?

In order to answer the initial questions, wrong assumptions were explained through library studies. And then, the role of wrong assumptions in the decision-making process was discussed. And by reviewing an example of the effect of wrong assumptions in making wrong decisions, this process was explained.

Then, to answer the key question, the problems were defined using library studies and numerical databases (Forrester, 1980). And then its big policy-making mistakes were explained. And then, through interviews with experts, the governing structure of these mistakes was identified. Finally, the causes of these mistakes were identified. And the wrong assumptions behind these mistakes were identified. Experts also confirmed the validity of the model (validity of CLDs). It should be noted that a small Group Model Building (GMB) method with 6 experts has been used to analyze the data to define the problem and construct the model and conclusion. These 6 experts were 2 economists, 1 specialist in the field of gasoline, 1 expert in the field of steel, a manager of a science and technology park, and a manager of a knowledge-based company in the science and technology park. Three 2-hour sessions were held for the group interview, which lasted 6 hours.

3. Examples of wrong assumptions and their effects

In this section, the effect of wrong assumptions in decision-making and policy-making is explained by mentioning various examples in the field of macroeconomics (gasoline, steel) and knowledge-based economics (science and technology parks).

3.1. Pricing with wrong assumptions in the economy: the price of gasoline

Due to inflation, the government increased the price of gasoline at the beginning of each year until the Islamic Consultative Assembly, contrary to the government's opinion in 2003, for the welfare of the people, considering that the gradual increase in gasoline prices is inflationary and that the economy is commanded. Practices decided to adopt a policy of stabilizing the price of gasoline. In other words, as shown in Figure 5, from 1997 to 2004, the price change at the beginning of each year increased based on inflation (gradual change policy), but with the approval of the Price Stabilization Law in 2004, the price remained stable from that year to 2007. Statistical Centre of Iran, Website; Double-digit inflation and the stability of gasoline prices, as shown in Figure 6, increased the trend of gasoline consumption (Haji Gholam Saryazdi, 2020). As both the diagram in Figure 5 and the structure shown in Figure 7 show, the wrong assumption that "change in gasoline prices is commensurate with inflation" caused the country to experience large fluctuations in gasoline prices because, after a while, the real price of gasoline remained stable. Because inflation in the country is in double digits, the nominal price is constantly increasing, which reduces the government's ability to maintain the real price due to increased gasoline consumption, smuggling it abroad, and increasing its subsidies, and the government is forced to increase its price to close prices. It is called the price, which is a big fluctuation, which is inflation. Therefore, here, too, the increase in the price of gasoline in proportion to inflation, which is itself a consequence of inflation, is considered the cause of inflation, and the policy-maker has made this wrong assumption and made the wrong decision and created unhealthy conditions in this field in the country.

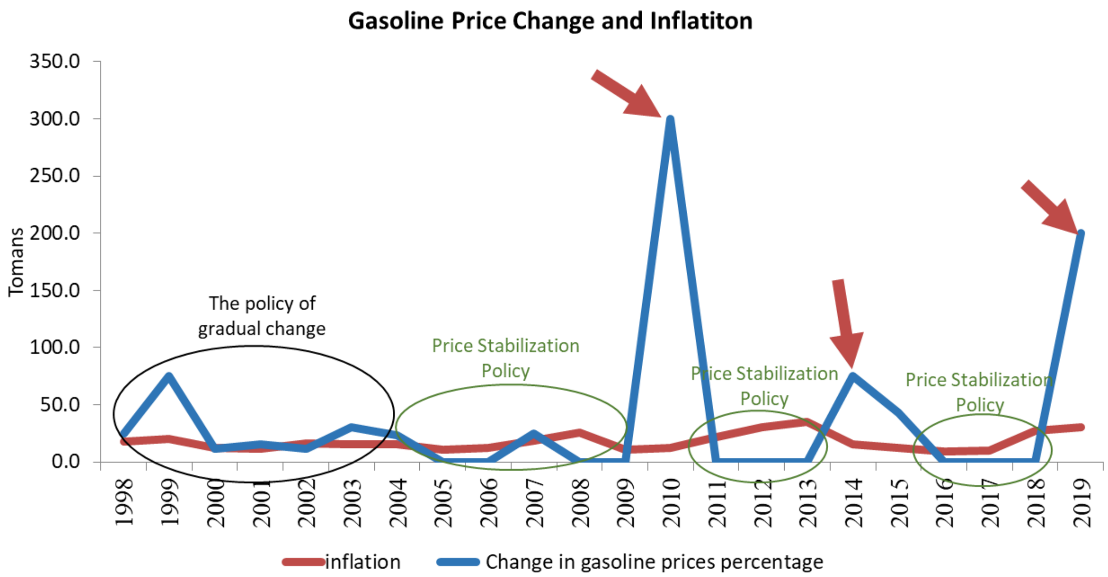

Figure 5: Gasoline price behavior and its changes in the light of different policies

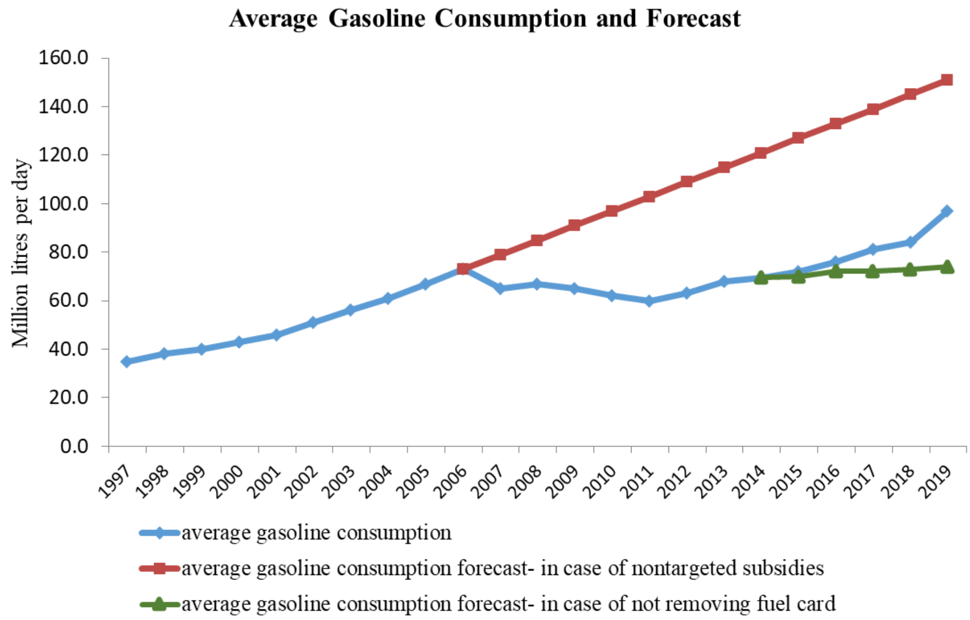

Figure 6: Gasoline consumption trend (Haji Gholam Saryazdi, 2020)

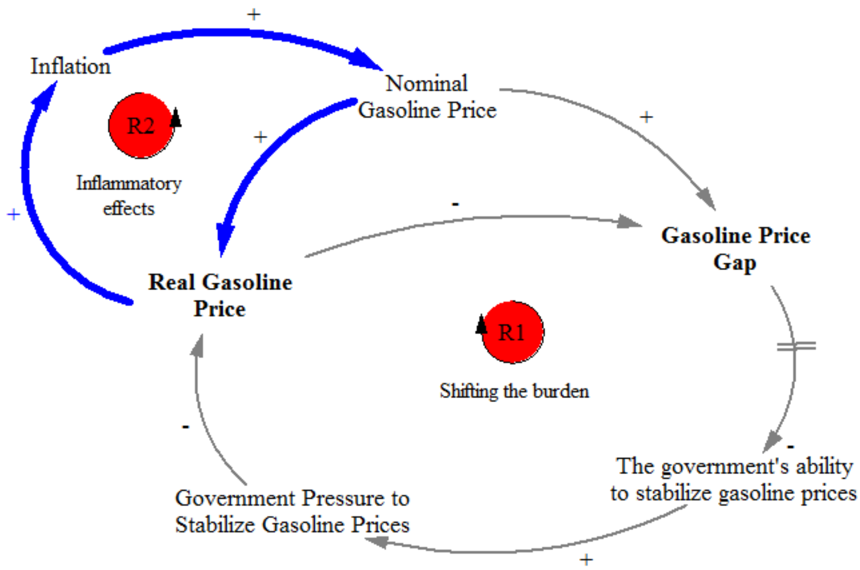

Figure 7: General pattern of wrong assumptions about gasoline prices (Haji Gholam Saryazdi, 2020)

3.2. Pricing with wrong assumptions in economics: Steel style

The important point in discussing assumptions is that it has nothing to do with the person or the organizer of the assumption, and a person may have an assumption in one field or subject that he or she does not have in another field or subject. For example, in the case of gasoline, governments have sought to change the price of gasoline. The parliament has stabilized the price, while in the steel chain supply and demand regulation that the government approved and announced, the government is in favor of price stabilization and the parliament is against it.

The price per kilogram of the beam in the market and commodity exchange was higher than the world price until mid-1999, which was lower than the world price curve after applying the steel method. Currently, the price of beams in Iran is lower than their real value compared to other steel sections. Therefore, as it is clear in Figure 8, this assumption and the associated decision cause the distribution of astronomical rents because due to government intervention in determining the base price of steel products, which is about 50% cheaper than world prices, about 80,000 billion tomans of rent is distributed (equivalent to twice the cash subsidy budget of the country). On the other hand, this outbreak reduces the exchange rate on the export side due to the impediment to the export of steel ingots by making the export license conditional on ensuring that domestic demand is met. At the same time, more than three times the country's need for long steel section capacity has been created (ifoolad Site, 2020).

In other words, although in the short run, with the supply of steel at a lower price and restrictions on exports (more for domestic supply), the real price of steel decreases (B1 Loop), but with the rent created and sales at a price lower than the nominal price, while production decreases, exports decrease (R2,3). By strengthening and stimulating speculators, false demand increases (Loop R1). Eventually, it leads to more inflation, which after the passage of time and the reduction of the government's ability to stabilize the price and create various problems, including the closure of steel factories, it will lead to price fluctuations and reduce the difference between real and nominal prices, and a pattern similar to the price of gasoline will be created.

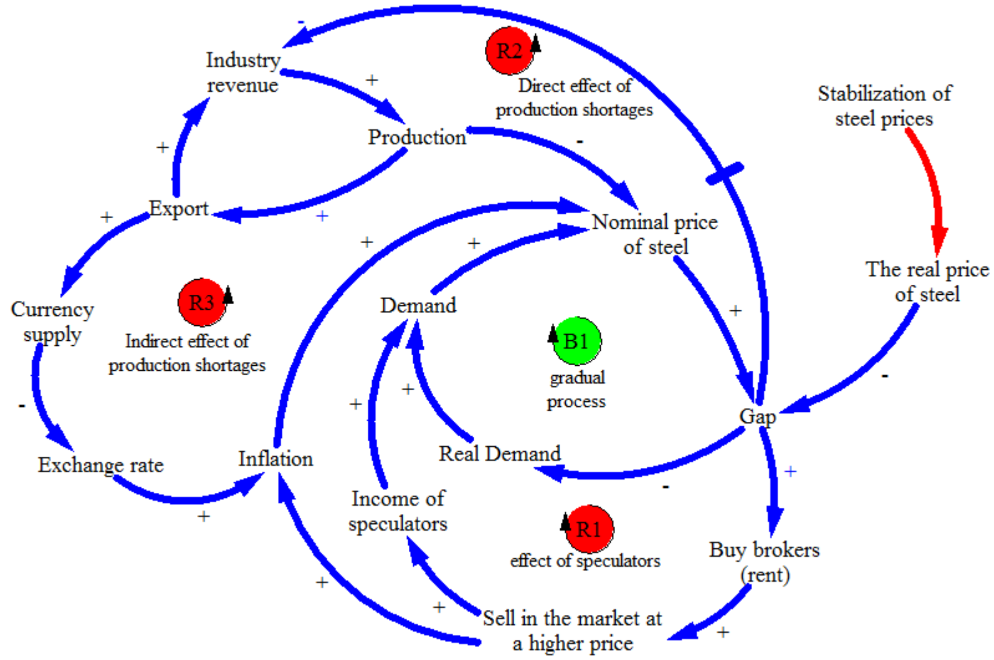

Figure 8: General pattern of wrong assumptions about steel outbreaks

3.3. Crocodiles with big mouth and small hands and feet

The previous examples showed how wrong assumptions in macroeconomics could lead to wrong decisions and policies and cause a lot of suffering and problems for the country. This section provides an example of knowledge-based economics and policy-making in science and technology parks and knowledge-based technology companies.

Some managers of science and technology parks have the assumption that the mission of parks is to create and support technology companies; in other words, " Being company-oriented is the main mission of the park." This assumption causes, as shown in Figure 9, to provide permanent support to companies, including tax exemptions, providing financial facilities, having priority over projects over other companies, and etc. (Haji Gholam Saryazdi and Poursarrajian, 2021), and companies are always in the same environment. They are closed, isolated, and artificial, meaning that park-based and knowledge-based companies do not understand the realities of the market, and even though they are large companies, they depend on the park and expect to receive this support. Such companies are called "crocodiles with big mouths and small hands and feet." Therefore, they need a permanent presence in the parks. In other words, instead of these companies being privately managed and contributing to the country's economic development, due to this wrong assumption, they have become private companies (apparently private but dependent on the government and oil money) and increasingly dependent on the government and oil. And weaken the economy.

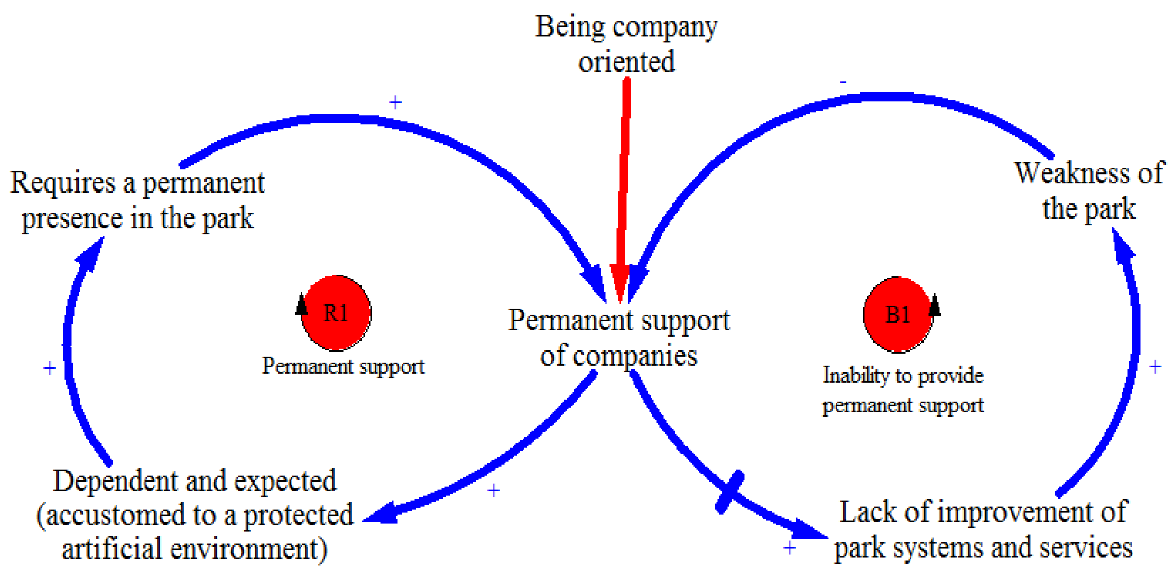

Figure 9: General pattern of wrong assumptions about the main mission of science and technology parks

4. Solution

As mentioned, assumptions play an important role in decision-making and policy-making and practically make people's lives that if the assumptions in people's minds are wrong, they will create a bad situation. Therefore, if these wrong assumptions are not properly identified and corrected, they will cause the recurrence of these sufferings. On the other hand, it was said that assumptions are both unknown, and there is a prejudice toward preserving them, so it is necessary to provide a way to recognize and correct them.

In this regard, experts in the field of learning, especially organizational learning, such as Argris (1977) have proposed a two-loop learning method for correcting assumptions (Argyris, 1977). From Argris's point of view, learning means identifying and correcting mistakes. One of his famous and applied theories in the field of learning is the concept of one-cycle learning versus two-cycle learning.

According to Figure 10, single-loop learning occurs when a problem arises, the first step in solving the problem is to find another strategy that is consistent with the basic assumptions and in line with their realization. In other words, basic assumptions and assumptions are used before they are questioned. But in two-cycle learning, the basic assumptions governing the problem are carefully and critically examined. This way of learning may lead to the transformation of key assumptions and values and thus change the framework for forming strategies and consequences.

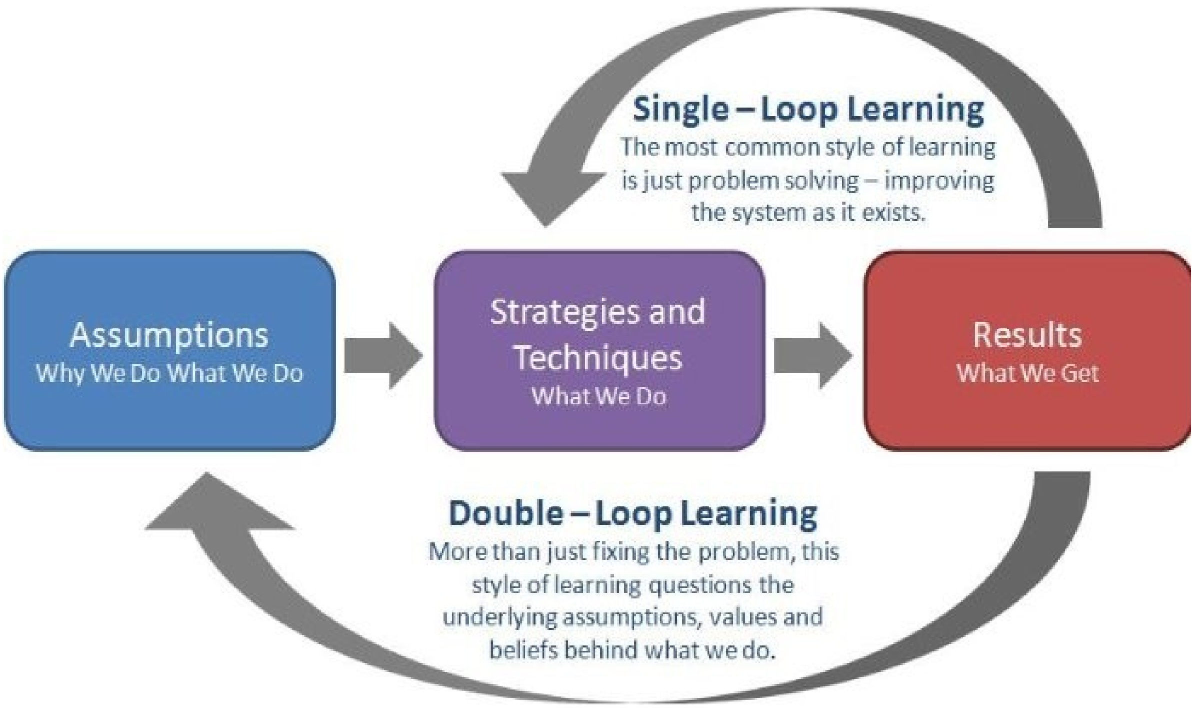

Figure 10: Single and double-loop learning (Argyris, 1977).

Therefore, to deal with wrong assumptions, it is necessary to identify the information related to the problem and the data indicating the error in the first problem according to Figure 11, in the first and the second loop, by analysing the causal structure governing it. In other words, in the first stage, by drawing behavioral diagrams over time, the problem resulting from the decisions made is explained, and then in the second stage, the cause-and-effect structure and the assumptions behind the decisions are identified, and the assumptions are corrected.

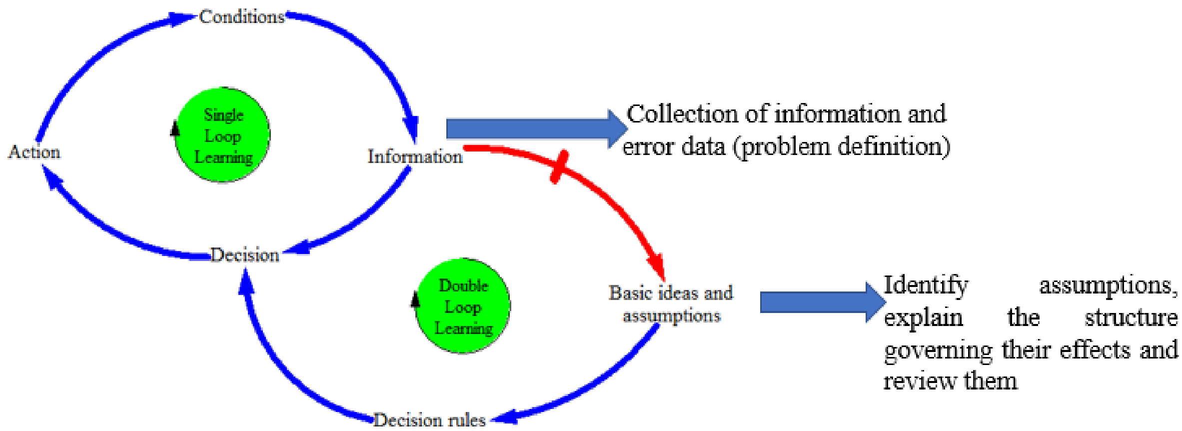

Figure 11: Two-stage correction of assumptions

For example, in the example of gasoline, as shown in Figure 12; First, by collecting information, the behavior of gasoline price behavior should be drawn, and then the governing structure should be identified, and the effect of the governing assumption should be explained, and then the correct assumption should replace the wrong assumption.

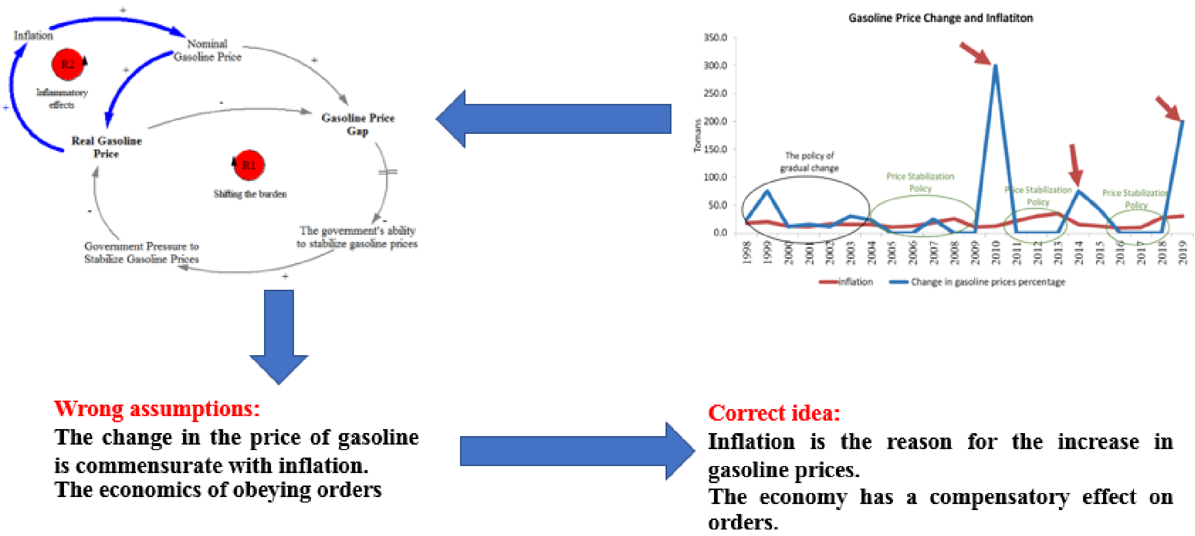

Figure 12: Correction of wrong assumptions in gasoline pricing policy

5. Conclusion

As stated, assumptions are the basic assumptions or principles that make up the mental model, and by influencing the type and amount of information received from the problem (cognition effect) and determining the analysis model (analytical effect) play a major role in decision-making and policy-making and ultimately in shaping the world around. Thus, identifying key assumptions that have led to important decisions helps managers, decision-makers, and policy-makers to make better decisions and correct mistakes. On the other hand, assumptions are gradually formed over time, and awareness of the existence of a particular assumption in mind and its effect (positive or negative) is low, and people are always prejudiced against it and do not see its errors.

In this article, while defining the assumption and expressing its role in the general decision-making process; By providing examples of wrong assumptions in the field of macroeconomics (gasoline, steel) and knowledge-based economics (science and technology parks) that have led to major policy mistakes, the role of wrong assumptions in decision-making was explained and the basic solution to counter wrong assumptions based on double loop learning were expressed. The proposed solution is in two stages of data collection (drawing the dynamic behavior of the problem) and identifying the governing structure, existing assumptions, and the effect of the assumptions to explain the correct assumption.

Based on the results of the article, the following policy recommendations are provided to improve policy-making and decision-making:

- When making policies and decisions, the assumptions of policymakers and decision-makers should be considered. In other words, people have to search for and understand

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their ideas.

- Policy-makers and decision-makers need to check the accuracy of their assumptions. For example, the assumptions that "the value of the national currency is equal to the exchange rate" and that "a gradual increase in price causes inflation" and that "the government can run the economy by order" are false.
- Policy-makers and decision-makers need to examine the impact of their assumptions on decisions.

Policy-makers and decision-makers to get the right assumptions is better to use the opinion of experts as a group to critique and correct the assumptions of different people. And the final decision and policy should be made based on the consensus of different people with the right assumptions.

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Space Orbiter Engineering Change Control in Context of Systems Engineering

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A B S T R A C T

In this research, an engineered process with a new approach to change control is presented and implemented on a complex space product. This approach involves using design constraint levels in a combination of two design structure matrix (DSM) structures and a systematic process for controlling changes. The system process includes the use of the system change evaluation code, how to create the transfer model, and the management evaluation of the requested change. While using similar existing methods in the literature, this paper provides a systematic approach to apply the knowledge of the designers of a space project to guide change control of large engineering projects, including managerial change control decisions and how to identify the best path for the change control process. Finally, a space orbiter has been selected for a brief implementation of a case study. The comparative results show the benefit of the proposed approach.

Keywords

Change control, Change evaluation code, Trade-off study, Transfer model, Design matrix.

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1. Introduction

Engineering change is a major and significant activity in industrial projects. Engineering changes exist from the explanation of concepts to the design and implementation process, construction and operation, and even after-sales service (Tang et al., 2008). The different phases of the life cycle of an aerospace product are described in (Kapurch,2010). However, all the art and science of systems engineering should be applied in the design phases because changes in subsequent phases cost up to 100 times more. Also, about 90% of the product life cycle cost is affected by the variant finalized at the end of the preliminary design phase (Anderson, 2014). On the other hand, various researches state that "design changes" constitute one-third of engineering design capacity (Kanike and Ahmed, 2007; Fricke et al., 2000; Maier and Langer, 2011). Comprehensive product management is the key to success in business management, and change management is at the core of comprehensive product management. An engineering product consists of many components, subsystems, and the relationships between them, and making a change in a component or subsystem creates a chain of changes in the product. However, the usual situation of product design and production shows that the core of engineering changes is mainly focused on tracking and storing engineering changes. There is a lack of quantitative analysis and evaluation of these changes (Tang et al., 2010). Among product design activities are "engineering changes" that can significantly propagate and impact product development (Li et al., 2012).

In this article, requirements are related to many components, and each of these components can be an Originating change Component (OCC) in a way that meets their requirements or changes. An initiating component of change is related to several " Change Propagation Path (CPP)" (Tang et al., 2016). This article develops how to search for optimal change propagation paths for " Change Requirement ". A review of articles from 1981 to the present in Table (1) lists the major articles that have used the above methods to control change.

As can be seen, the "matrix-base" method has the most use, and the "model-base" method has the least use in engineering change management. The theoretical model is not always achievable or not always complete, and therefore it is necessary to extract some kind of dependency model (Hamraz et al.; 2012). This model is much simpler than a theoretical model that focuses on specific aspects of the product or system. This model does not require precise equations and logical rules between parameters but simultaneously allows us to achieve 1- direction of the changes and 2- predict new values.

1. Comparison of different methods in control of engineering changes (Masmoudi et al., 2017)

Row	Paper Name	Change Characterization			Resolution method			Propagation Visualization		
		Likelihood	Qualitative Impact	Quantitative Impact	Matrix -based	Model -based	Algorithm -based	Propagation Tree	Propagation network	Change Propagation Index(CPI)
1	Cheng and Chu (2012)			*	*				*	*
2	Chua and Hossain (2011)		*		*	*				
3	Clarkson et al., (2004)	*		*	*		*	*		
4	Cohen et al., (2000)		*		*	*	*		*	
5	Flanagan et al. (2003)		*		*				*	
6	Giffin et al., (2009)	*			*			*	*	*
7	Hamraz et al. (2012)	*		*	*		*	*		
8	Hamraz et al. (2013)	*		*	*	*				
9	Keller et al., (2005)	*		*	*			*	*	
10	Kim et al., (2013)	*		*	*			*	*	*
11	Kusiak and Wang (1995)		*	*			*		*	
12	Li and Zhao (2014)	*		*		*			*	
13	Li et al., (2016)	*		*		*			*	
14	Oduncuoglu and Thomson (2011)	*			*	*				
15	Rutka et al., (2006)	*	*		*			*		
16	Steward (1981)				*					
17	Yang and Duan (2012)			*					*	*
Total papers		10	5	10	13	6	4	6	15	4
Present Paper		*	*	*	*	*	*			*

In the pure model-based method, existing models are used to specify new values as well as the direction of the changes. While in the pure dependency model, it is not possible to determine new definite values, but by searching for the direction of change, these values can be predicted, and the end path of propagation of changes can be determined and predicted (Masmoudi et al., 2017). In this paper, with the help of methods and techniques, the effective phases of design are given serious attention. This is one of the differences between this research and similar ones.

As seen in Table (1), in addition to the various techniques developed in the study of engineering variations, structural design matrixes have been widely welcomed to maintain the relationship between the parameters. DSM is a good tool for mapping information flow and storing its effects on the product (Tang et al., 2008). The strengths of this study compared to similar studies are examined:

1- In most of the work done, less control and management of engineering changes is in the important design phases, while the current research focuses on the design phase.

2- Combining product and activity[1]matrixes and creating matrixes CA-DSM[2]that create sensitivity matrixes by combining activities and product elements. These matrices help the chief designer predict propagation changes.

3- A combined work of most methods listed in Table (1) has been done.

4- Relying on the knowledge of the chief designer in parallel with the change control software in controlling the propagation of change and achieving the most optimal path of change.

5- Implementation flexibility in engineering projects.

6- Defining several indicators to quantify the control of change propagation and choosing the most optimal path of change in the areas of the probability of effect, resources used, time, improvement of requirements, and bottlenecks.

7- Emphasis on the role of "Configuration Management Center[3]" as a command center for change control in an industrial environment.

2. Problem statement

Engineering Change Management (ECM) is a significant activity in product design and development (Kanike and Ahmed, 2007). This paper presents change management planning for complex systems such as aerospace products. The operation in many papers is not a suitable solution for complex systems and can only be implemented for products with low interactions. Difference control changes in complex systems such as aerospace products are summarized as follows:

[1] Activities are derived from design process
[2] Components Activity- Design Structure Matrix
[3] CMC

- Very high diversity of system parameters
- Extensive interactions between different components
- Extensive knowledge of the relationship between components
- Interrelated parameters with each other
- Many limitations of design and manufacturing

The above items complicate the process of predicting change control. If we control the changes according to the usual models, we will deal with a large chain of changes without an endpoint. Therefore, the function of this activity can be summarized in the following cases:

- Development of conceptual design (propagation of design changes)
- Product life cycle controllability
- Management control of changes in design processes
- Tangible relationship between all sub-sectors involved in project activities
- Change control in products with high and complex interactions

3. Problem-solving methodology

In this paper, the structure of change control planning for complex systems consists of six parts:

- CA-DSM matrix (interactions between parameters)
- Levels of parameter constraining in the design process
- Engineering change evaluation code (estimating the number of interactions between CA-DSM matrix parameters and identifying the sensitivity range of all parameters)
- Transfer model between parameters
- Measuring change from the perspective of the configuration management center
- A comprehensive change control algorithm

The logic of this research is also shown in figure 1. In column one, design, technical management, and optimization are observed without using systems thinking. In the second column, the proposed systems thinking tools are included, and in the third column, the new and modern combination of the traditional method and systems thinking can be seen. In the fourth column, the selected technique (from the set of techniques of the third column), which is used in this article, is also mentioned.

For example, in the second row, traditional design without technical management plus systems thinking leads to systems engineering. We have used the change management process from among the various processes and tools of systems engineering, which finally combines the three selected techniques for MSDO Change control.

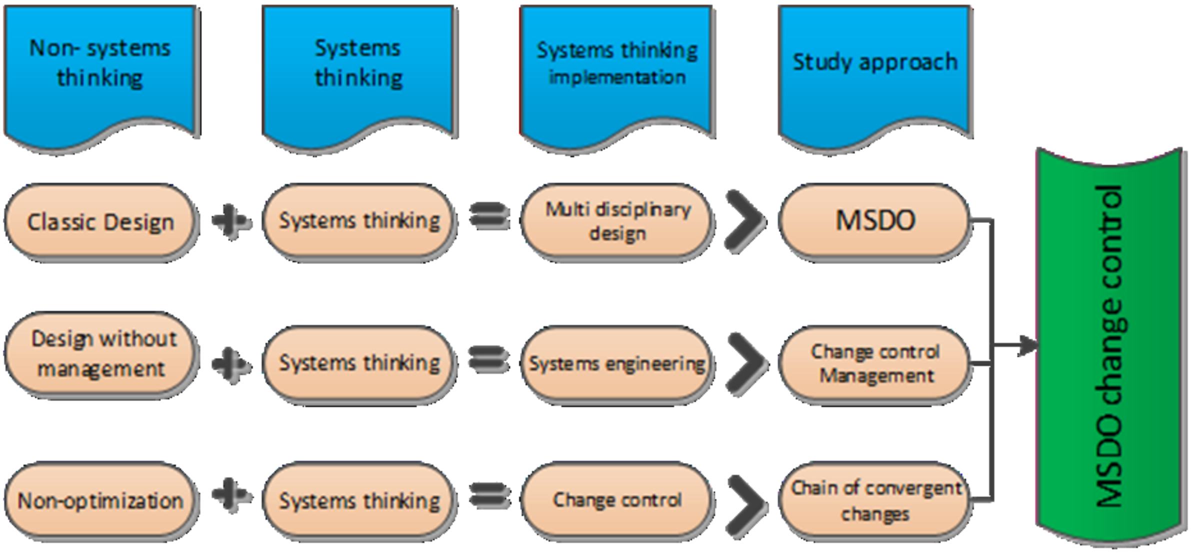

Figure 1. The Logic of this research

3.1. Matrix of component activities[4]

The DSM method (using structural design matrixes) is an information exchange model that allows the designer to determine the relationship between system parameters by data exchange (Eppinger and Browning, 2012). The probabilities and effects of changes between system components are stored in the DSM to determine and detect the variability of complex engineering systems (Clarkson et al., 2004; Koh et al., 2013). In this paper, two models of DSM matrixes are used in combination. Combining product and activity[5] matrixes and creating combined matrixes CA-DSM[6] that create sensitivity matrixes by combining activities and product elements. The reason for using a combined matrix is easier change control for complex products. The relationship between components in product DSM and activity DSM are explained. The matrix containing these two properties, called the Product Activity Design Structure Matrix (CA-DSM), is shown in Figure 2.

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[4] CA-DSM
[5] Activities are derived from design process
[6] Components Activity- Design Structure Matrix

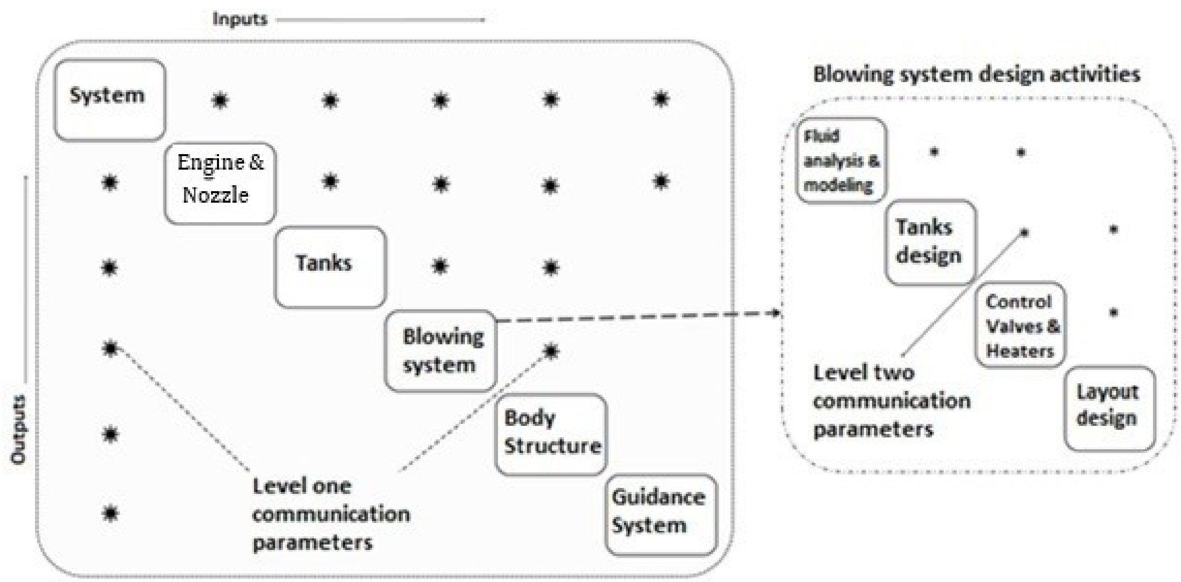

Figure 2. Product Activity Design Structure Matrix (CA-DSM) of Space Orbiter.

Level 1 parameters include the parameters relating to the subsystems or specific components in the large matrix diameter. Level 2 parameters include the parameters relating to the various activities within the small matrixes for each large matrix component. The design of each component in a subsystem can be the result of the work of several experts. However, a team or an individual activity is a parallel activity. For this reason, choosing such a matrix helps to accelerate and simplify relationships to control change.

In the CA-DSM matrix, these two properties are:

1. The main matrix contains the relationship of level 1 parameters, which uses the DSM logic of the product.
2. The matrix of each subdivision includes the relationship between the activities of that subsystem and the relationship between the level 2 parameters.

The strength of using the CA-DSM combined matrix is the ability to simultaneously switch between activities - work processes and product elements at the subsystem and system levels.

3.2. Design model

Each design phase (conceptual, preliminary, detailed) consists of several major sections (Hamraz, 2013; Plehn, 2018), including a set of system parameters. For example, design propagation levels can be defined in such a way that it first includes constraints on the main dimensions, then geometric constraints, then quantities, and finally tolerances (Masmoudi et al., 2017). The comprehensive design model using the Figure 2 matrix is shown in Figure 3:

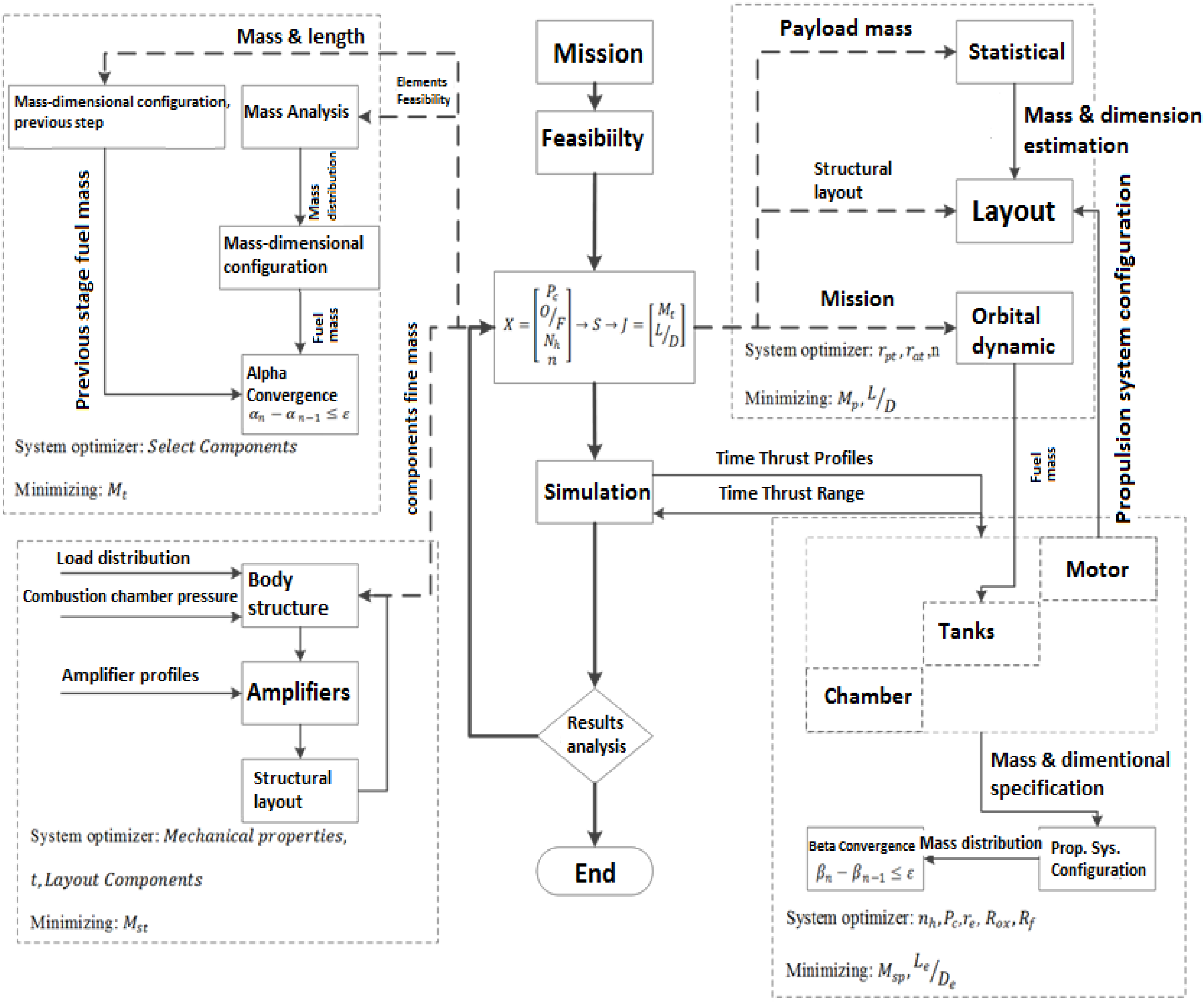

Figure 3. Design of space orbiter to implement change control in systems engineering processes.

3.3. *Engineering change evaluation code*[7]

Sensitivity of design changes should be developed in parallel with the design process (Li and Zhao, 2014). As the design process moves forward, so does the process of sensitizing change to affected activities. Failure to do so will lead to the closure of the change loop, ultimately leading to increased time and cost and even project failure.

A change in any of the Level 1 parameters can lead to a change in the other Level 1 parameters as well as the Level 2 parameters in proportion to the Level 1 parameters. At the

[7] CEC

same time, it is possible to develop code that converges all the requirements of the changes, considering the constraints. Of course, in developing this model, the work of the chief designer is difficult and requires a high level of knowledge. Without such knowledge, this model would be very time-consuming and costly. Figure (4) shows the CEC software algorithm:

The code consists of the following three parts:

- The first part of the sensitivity part: In this part, the sensitivity of all the parameters inside the matrix is done.
- The second part of the design: In complex systems, specific and limited relationships can be obtained for mass-dimensional configuration. In this section, the use of relations (system equations) for the relationship between level one parameters and system equations for subsystem design is for the relationship between subsystem parameters. In this section, the range of change of all system parameters due to the change of one parameter is calculated.
- The third part of the convergence part: In this part, the relationship between all level one and two parameters is converged in the design process, and the minimum changes of the parameters compared to the changed parameter are obtained. The most important output of the software is the designer achieving the results of the review of changes.
- Configuration management center review section: In this section, it achieves the desired results according to the algorithm in Figure 4.

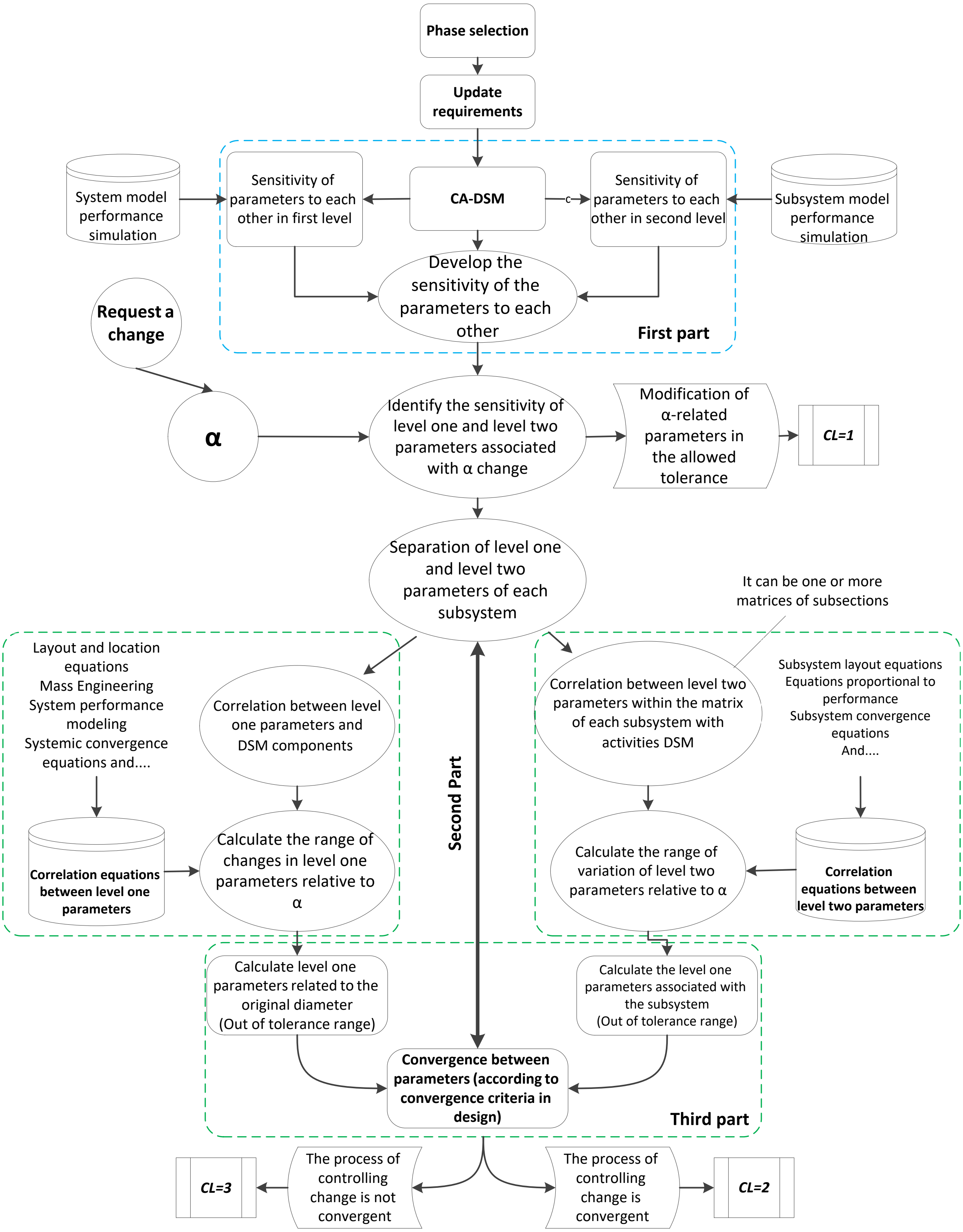

Figure 4. Evaluating Changes in the Design Process Algorithm

3.4. Engineering change transfer model

Finding the correct change propagation path for products with complex relationships is very difficult (Tang et al., 2016). It should be noted that the use of a linear and serial algorithm model, control and management of changes in projects with a variety of parameters, elements, relationships, and different environmental conditions, face serious problems, and it is necessary to develop a suitable algorithm. To eliminate this shortcoming (Hamraz et al., 2013). In these projects, methods and algorithms should be sought that have the necessary flexibility in the face of diverse and complex specialties and subsystems (Hamraz et al., 2013). In order to create a proper transfer path in complex systems, in addition to the need for the knowledge of the chief system designer, the knowledge of the chief designers of the subsystems and system tools is needed to create an integrated model of the change transfer algorithm. The algorithm for creating a transfer model for complex systems is shown in Figure 5.

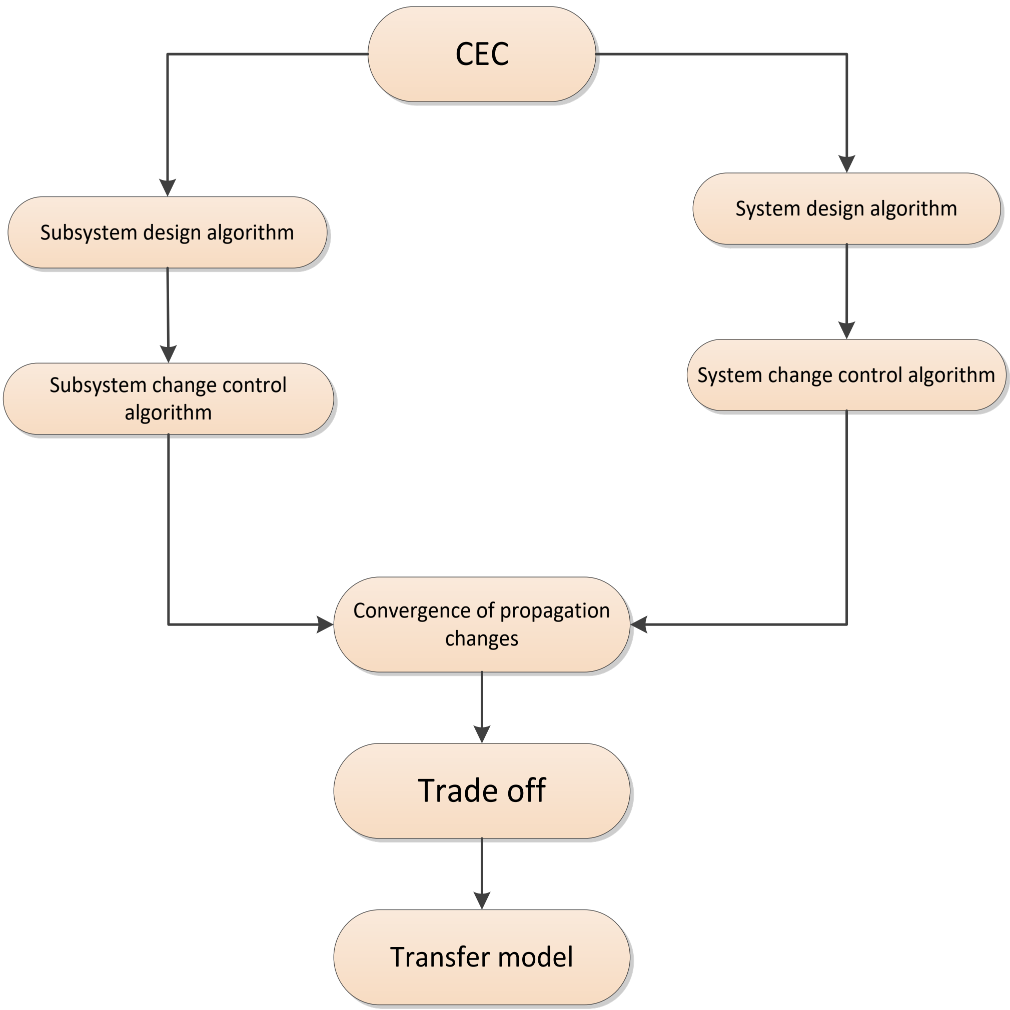

Figure 5. Transfer Model of Complex Systems

According to the algorithm in Figure 5. the creation of the change control algorithm is obtained as a result of the expertise of the head designer and the use of the following:

- CEC software for the range of changes caused by the change
- Convergence algorithm designed to create seamless relationships between level one parameters
- CA-DSM matrix as a roadmap for all possible interactions paths between parameters

Also, the knowledge of controlling subsystem changes is obtained as a result of the expertise of subsystem designers and the use of the following:

- The DSM Activities matrix of each subsystem
- Convergence algorithm designed to create seamless relationships between level parameters of two subsystems
- Analysis of laboratory and engineering tests

Knowledge of change control at the system level and subsystems for each change request leads to a system change control algorithm. The trade-off of the possible paths by these algorithms together and convergence between information exchanges create the transfer model (Plehn, 2018; Acar et al., 2005).

3.5. Configuration management center

In the design phase, a present process for the amount of workload cannot be defined. Therefore, to define the cost, time, and workload of all changes, the configuration management canter needs to achieve different dimensions of the impact of a change in the product life cycle (Tang et al. 2016). The questions and the effect of each of the following should be specified for the configuration management center:

- ✓ Is this change to improve the requirements?
- ✓ Is this change due to design constraints such as lack of space or assembly problems?
- ✓ Is this change due to a low level of technology, lower cost, or inability to purchase some parts?
- ✓ Is this change due to other changes in the product?
- ✓ Is this a bottleneck, and should it be done?

The relations in Table 2 are used to qualify these questions.

Table 2. Comparison of different methods in control of engineering changes

How to produce	Symbol and impact number	Coefficient Name
Chief Designer	a (1..4)	Workload
project manager	b (1..4)	Consumer resources
Related parts	c (1..4)	Time
Simulation Chief Designer	if $+ \rightarrow$ d (0.25..1); $- \rightarrow$ d (1..4)	Improve requirements
project manager	if $+ \rightarrow$ f (0.1..1); $- \rightarrow$ f (1..2)	Throat

The following points are written to explain Table 2:

- ✓ The selection of value of the impact number is obtained qualitatively by the relevant people.
- ✓ Values greater than 1 indicate a greater impact intensity, and values less than 1 lead to positive effects of change.
- ✓ The head designer obtains the workload coefficient after using CEC.
- ✓ The project manager determines the coefficient of consumption resources after announcing the opinion of the involved parts.
- ✓ The time coefficient is determined after announcing the time required for each sub-section to perform its specific activity.
- ✓ The requirements improvement coefficient is obtained after reviewing the head designer or the person in charge of performance analysis (simulator) to influence the change in the improvement requirements according to the customer.
- ✓ The bottleneck coefficient is obtained due to the forced effect of a change to eliminate the bottleneck or the lack of suitable materials, parts, etc.

The probability value of the effect is obtained from the following equation:

$$PE^{8} = a \times b \times c \times d \times f \quad (1)$$
$$CT^{9} = b \times c \quad (2)$$

Depending on the effect parameter probability (PE) and time and cost (CT), a small change can be made to the managerial decision. PE quantifies the impact of the requested change on the project and quantified CT measures the amount of time and cost involved.

[8] Probability effect
[9] Cost and Time

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4. Change control algorithm

A change request can be made by any of the subsystems. This request is made for one of the following reasons:

- Propagation of design failure structure
- Reduce costs
- Layout restrictions and space involved
- Improve customer requirements
- Optimization in design

In the first step, the change request is sent to the configuration management center, which reviews the change request according to the effects of the change. Tracking and execution of the change control management algorithm in Figure 6 are done by the configuration management center. This algorithm is performed according to the needs of the project manager, system head, and personnel working on the project. The comprehensive change control management algorithm consists of five main parts:

1. Configuration and sensitivity of all matrix parameters to each other
2. Limiting levels of each part of a design phase
3. Use of CEC software
4. Trade-off possible ways (transfer model)
5. Management evaluation in order to manage the life cycle

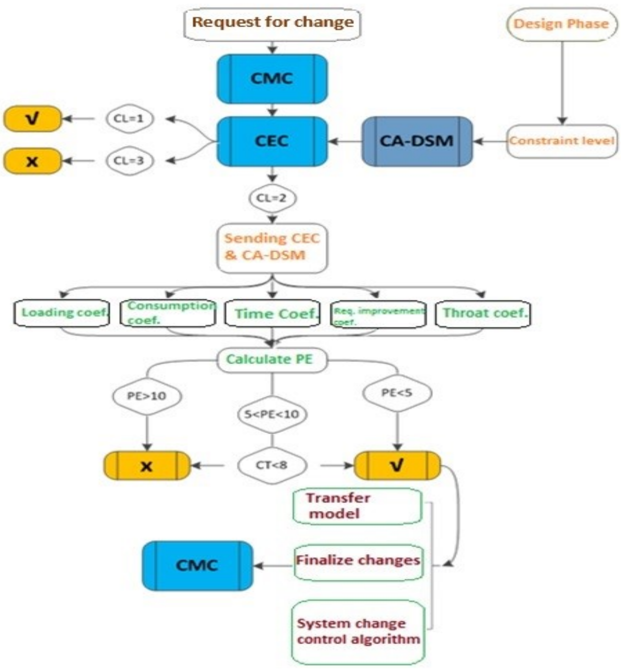

Figure 6. Comprehensive change control algorithm for large engineering projects

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5. Results of a case study

The CA-DSM matrix is shown in Figure 2 for the orbital transmission block. The execution process for a new change request is given using this matrix.

Change request α: 10% increase in nozzle length due to proper accuracy in rotation of the nozzle according to the requirement of the operator connected to the nozzle (passing the system requirement)

According to the algorithm of Figure 6, after receiving the change request from the configuration management center, the above activities are performed in order:

1. Compilation of CA-DSM matrix (Figure 1)
   - ✓ Design phase: preliminary design
   - ✓ Leveling: Total dimensional parameters
2. Use the CEC program to assess the sensitivity of the effects of change and identify the system parameters involved
   - Part 1 of CEC: Development of sensitivity of all parameters to each other by functional simulation of subsystems, which is available as an example in references (Nosratollahi et al., 2015a) and (Ali Mohammadi et al., 2013).
   - Part II CEC: Calculating the range of changes in level one parameters relative to the change in α and calculating the range of changes in level two parameters relative to the change in α in the subsystem algorithms (Nosratollahi et al., 2015) and (Nosratollahi et al., 2016).
   - Part III CEC: Convergence of changes in the design process using the β convergence coefficient criterion (Nosratollahi et al., 2016).

$$\beta = \frac{\text{dry mass}}{\text{dry mass+fuel mass}} \tag{3}$$

Preliminary result of using CEC software to change α, value CL = 2

3. Send CEC information and CA-DSM sensitivity by the configuration management center to the relevant parts.
4. Calculation of configuration management coefficients according to Table 3:

Table 3. configuration management coefficients

Coefficient name	Quality level	Quantification
Workload (total activities + complexity of matrix interactions)	Subset level = 1 Subsystem level = 2 System convergence level = 3 System heterogeneous level = 4	a=3
Resources (added time + cost to the project)	Less than 0.1% = 1 Less than 1% = 2 Less than 5% = 3 More than 5% = 4	b=2
Time involved parts (change in project Gantt time)	No change = 1 Less than 0.1% = 2 Less than 5% = 3 More than 5% = 4	c=2
Improve requirements	No effect = 1 Positive effect = less than 1 Low negative impact = 2 High negative impact = 3 Large change in a main requirement = 4	d=0.8
Throat	Removable in the range of resources = less than 1 Irresistible in the range of resources = more than 1	f=1

5. Calculate the probability values of the effect and the effect of time and cost:

The value is PE = 6.4 and CT = 4, and the change is confirmed by CMC.

6. The system change control algorithm is obtained according to the model of Figure 6 according to Figure 7. This algorithm is a significant process to avoid a chain of multiple and divergent changes.

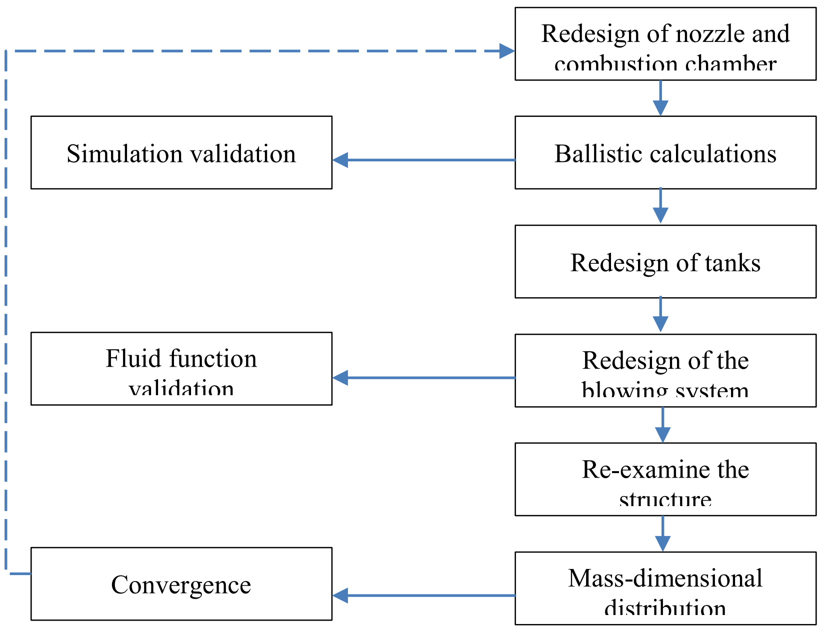

Figure 7. Systemic Change Control Algorithm for α Requested

7. Transfer model: Using the algorithm of Figure (7) and CEC software, the best transfer method is obtained according to Figure (8).

This model is the result of the Trade-off process of the parameter cycle in the design convergence cycle with the criterion of the minimum chain of changes.

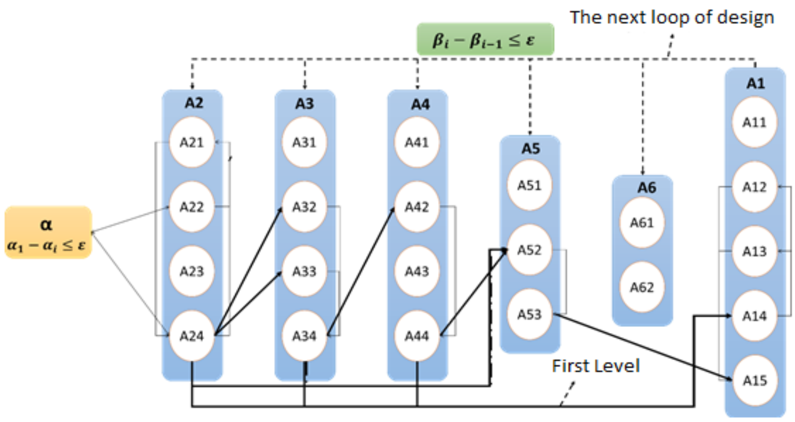

Figure 8. Transfer Model for α Requested

In this figure, A1 = system, A2 = motor, nozzle and chamber, A3 = tanks, A4 = blowing system, A5 = internal structure and body, and A6 = guidance system, and also Aij = sub- are activities related to each subsystem.

Control of changes of a 10% increase in nozzle length demand ultimately results in a 2% effect of dimensional change in the propulsion subsystem, a 5% effect of oxidation tank dimensional change, and a 3% effect of oxidation tank dimensional change. Also, other changes have changed in the form of subsequent changes following the chain of changes.

Table 4. Change system parameters

Rows	System requirement	Before change	After change
1	Convergence coefficient	0.1249	0.1251
2	The final crime	3.391 ton	3.397
3	Total crime	16.64 ton	16.648
4	Nozzle expansion ratio	38.75	39.9
5	Engine length	2.04 m	2.0818
6	Number of blow tanks	6	7
7	The radius of the tail tanks	257.2 mm	244.31
8	Fuel tank height	0.72 m	0.69
9	Fuel tank radius	1.18 m	1.19
10	Oxide tank height	1.18 m	1.16
11	Oxide tank radius	1.18 m	1.19

The process of changing the system parameters from the initial state to the post-change state is shown in Table 3. It should be noted that eleven change requests from the configuration management center (CMC) could have led to design divergence, and by using the current modern method based on system thinking, the best suggestions for changes in the optimization loops were extracted in such a way that the design is also converged.

6. Conclusion

Aerospace products have complex relationships in design processes. For this reason, the systematic design process of these products requires the development of appropriate and usable configuration management. The change control process is also one of the main activities in the propagation and development of product design. If you do not use a system logic, controlling any changes can complicate the design process and confuse project designers. Therefore, in order not to increase the time and high cost in the project design process and create a system logic to control change, an efficient and new approach was presented in this paper. This approach has been developed using systems engineering theory to improve design processes.

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Assessing the Barriers to Implementing Systems Thinking in Organizations Using Interpretive Structural Modeling

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ABSTRACT

Systems thinking is a useful approach to realizing and analyzing real-world phenomena. It helps us to study components of a system jointly rather than individually. In this regard, organizations need systems thinking to strengthen their holistic inclusiveness because it aids managers examine structures, patterns, and events about each other and not just observing events. Even though applications of systems thinking have been the center of scholars' attention, barriers, and factors that cause organizations to impair systems thinking have not appropriately been addressed and have been paid less attention. The passage of six decades of systems thinking as a theoretical-practical approach implies that it is appropriate that the field of growth and promotion of this effective thinking in the management of society and organization are given more attention by managers and decision-makers. Therefore, this study has been carried out to identify and analyze the barriers to systems thinking in Iranian organizations using the interpretive structural modeling (ISM) technique. This method is one of the system analysis methods and examines the interactions between system elements. In this study, after a comprehensive review of the research literature, 64 factors were extracted, combined as much as possible, and finally, the identified barriers were reduced to 7 categories. The results of the ISM model divided these 7 categories of factors (general barriers) into three levels of importance and effectiveness. Organizational, cultural, financial, educational, and personality factors were at the first level of influence. The mental factor took the second position, and the information factor took the third place. It can be mentioned that the managers should pay special attention to 5 factors in the first level as they are the most effective factors that concentration on them can lead to successful systems thinking in organizations.

Keywords

Systems Thinking, ISM, Implementation Barriers, Organization.

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1. Introduction

Systems thinking is a knowledge-based approach that focuses on recognizing, building, and predicting complicated systems as correlated individuals, not unrelated ones (Mambrey et.al, 2020). This way of thinking provides an effective methodology for socio-cultural systems in an environment full of confusion and complexity. There is no doubt that technological advancements in areas such as the Internet, GPS, power grid, and software APIs have led to increasing interdependence among different systems (Arnold and Wade, 2015). In this regard, organizations are interested in recreating their business models because of the increasing growth of technological and economic achievements (Hossain et al., 2020). To this end, systems thinking not only addresses the components and details of a system but also considers how the components interact as well as the interaction of components and the environment. In fact, this type of thinking seeks to understand the whole (system) and its components, the relationship between the components, and the relationship between the whole and its environment (Singh, 1990). Since our behavior is rooted in our system of thought, someone who has systems thinking also deals with issues systematically and, in his behaviors, seeks to identify the elements that make up the subject and the connections between these elements. In this way, the person who thinks in a system is not just looking for a set of features of the subject; rather, systems thinking helps him to look at issues comprehensively and systematically (Binesh, 2011).

Nonlinear thinking and a dynamic view of phenomena and consequences are the neglected points of managers' decisions in businesses and commercial and non-commercial organizations. Ignoring the inherent dynamics of phenomena leads to poor quality decisions that, instead of solving a problem, bring about new problems and challenges. Unfortunately, the number of such decisions at various levels of Iranian firms and organizations is not small, and even in our personal lives, we suffer from the consequences of linear and static thinking. (Mohammadi, 2017). Although many benefits have been mentioned for systems thinking, they are unfortunately not appropriately accepted and considered by Iranian organizations. There are many reasons for this, including the fact that humans are naturally inclined to deconstruct and prefer to remain in their past mental structures.

Moreover, human knowledge has been formed mainly based on partial mind and lead to ability reduction to understand many issues. This issue has also made "communication" difficult because, with the partial mind, it is not possible to produce communication tools (Khaldun, 2004). Unfortunately, in today's organizations, despite the significant progress they have made in human resources, there is no common language of communication between employees and members, which slows down their movement and progress. Also, organizations cannot identify and select the right solutions to many problems and issues. One of the reasons for the lack of communication between members, lack of identification of problems, and failure to provide appropriate answers to them, is the lack of systems thinking in organizations. In other words, systems thinking barriers are factors that impede the implementation of systems thinking.

Various researches have studied systems thinking barriers such as traditional management, communist and mechanistic perspective, lack of interdisciplinary thinking, lack of voluntary communication to increase the systemic ability, and asymmetric information in the digital age (Basile and Caputo, 2017; Low, 2005). But a systematic view of barriers has received less attention, so it is necessary to study this subject more. Hence, presenting a suitable approach to identify and prioritize barriers can be beneficial. Until now, the implementation of systems thinking has not been investigated systematically; one of the best methods of systematic investigation of the factors affecting the implementation is the ISM method which will be used. Also, this method efficiently identifies the most effective and affected variables. To this end, this study intends to pay attention to this gap within organizations and identify the factors and barriers to implementing and assessing systems thinking in Iranian organizations. Then, it determines the relationship between these factors based on the opinions of experts in this field. In this study, it is determined what are the barriers to the implementation of systems thinking in Iranian organizations? and how much impact each of them has on this issue?

2. Theoretical framework

2.1. System

The system is a network of interconnected components that work together to achieve a common goal. The greater the degree of dependence on a system, the greater the need for coordination between components. A system is a set of elements that cannot be separated into independent components. We lose our properties if we use theories or systems to separate components. In this regard, the system has a general nature that is not possible with analysis alone. Understanding this is the first source of an intellectual revolution that changed the era and turned the four hundred years old era of "machine" into the era of "system", in the words of "Russell Ackoff " (Ackoff, 2009).

2.2. Systems thinking

Systems thinking is a view of the universe and its phenomena. The basis of systems thinking is the study of the component as a whole, not separately. In systems thinking, we do not separate the system from its environment and only examine the details as a single interaction and separately from time. This is because the performance of a system depends more on how its components interact than on how they function independently. Although the origin of systems thinking and the presentation of the general theory of systems was the science of biology, today, systems thinking is comprehensive and interdisciplinary thinking that provides an effective methodology for socio-cultural systems in an environment full of confusion and complexity. Systems thinking is a set of synergistic analytical skills used to improve the ability to identify and understand systems, predict their behaviors, and modify them to produce desired effects (Arnold and Wade, 2015). These skills work together as a system. The subtlety of this definition lies in its simplicity and application. Due to the lack of background on the nature of a system, this definition can be presented in an understandable way to an audience without a background in system science. The effort of systems thinking is summarized in two elements: reducing complexity by modeling systems conceptually and identifying and understanding nonlinear relationships (Arnold and Wade, 2015). Systems thinking is based on the premise that a system is a set of two or more components with three conditions: a) The behavior of each component depends on the behavior of each whole. B) The behavior of the components and their impact, on the whole, are interdependent. C) Each of the subgroups has an impact on the overall behavior, and the impact of any of them is not independent (Ackoff, 2009).

2.3. Elements of systems thinking

There are many definitions of systems thinking and its principles that, according to review studies (Arnold and Wade, 2015) in research background in the field of systems thinking definitions, including the following concisely::

1. Finding internal relations

This one is the most fundamental principle of systems thinking. It is capable of describing the key relations between different parts of a system. Without learning systems thinking, higher education cannot develop this skill.

2. Defining and understanding feedback

Some internal relations are combined to make cause-and-effect feedback loops. Systems thinking needs to understand and describe the feedback loops, and it also needs to realize how the feedback loops affect the system's behavior.

3. Realization of systems structure

Systems structure is made up of elements and the connections between them. Systems thinking needs to comprehend this structure. Although these elements specifically have not been mentioned in the classification of Hopper and Stave (2008) or Plate (2010), they can be called a combination of the two mentioned elements. And this is mentioned in other important works.

4. Detecting the flow and stock variables

Stock variable refers to the resources in a system. This variable can be physical, like the amount of paint in a bucket, or emotional, like the level of trust between friends. The flow variable is the changes in these levels. Other variables are modifiable parts of the system that affect stock and flow, like flow rate or a maximum of stock. Ability to distinguish between these stock variables, flow variables, and other variables and understanding their performance are important skills of systems thinking.

5. Recognizing and comprehending the nonlinear relationships

This element refers to nonlinear stocks and flows. Conceptually, this element can be grouped as different types of stock, flow, and variables. Nevertheless, the latter is indicative of linear flow. To avoid confusion, nonlinear flows are separated in this element.

6. Understanding the dynamic behavior

Relations, how to combine them with feedback loops, effects of these feedback loops and consists of stock variables, flow variables, and other variables are causes of creating the dynamic behavior in the system. This behavior is incomprehensible without training and understanding of the system (Plate, Monro, 2014). Emergence behavior, the term that is used to describe the behavior of an unpredictable system, is an example of dynamic behavior. Distinguishing between different types of stock variables, flow variables, and other variables also recognize and comprehend the nonlinear relationships, and both are the keys to understanding the dynamic behavior.

7. Reducing the complexity by conceptual modeling of systems

This element is the ability to model the concept of different parts of a system and observe the system in different ways. Performing this action goes beyond the systems models and, through various methods, such as reduction, transformation, summarization, and restatement, enters the process of intuitive simplification (Wade,2011). This skill can observe the system in different ways reducing the complexity.

8. Understanding Systems at different scales

This skill is similar to Barry Richmond's Forest Thinking (Plate, Monro, 2014). It includes the ability to recognize different scales of systems and systems within systems.

3. Literature review

The studies related to assessing systems thinking or its applications are stated in this literature. Basile and Caputo (2017) conducted a study entitled "Theories and challenges for systems thinking in practice ". They mentioned the challenges of implementing systems thinking in their research. Traditional management, communism, and mechanistic perspective, lack of interdisciplinary thinking, lack of voluntary communication to increase the systemic ability, and asymmetric information in the digital age are examples of challenges that are mentioned in this study. Jacob and Warschauer (2018) conducted a study entitled "Assessing systems thinking: A tool to measure complex reasoning through ill-structured problems". They provided a framework for operationalizing systems thinking. They mentioned two thinking indicators, measurement, and bias on tools. Richmond and Peterson (2001) conducted a study entitled "An introduction to systems thinking ". He introduced three indicators: operational, closed-loop, and nonlinear thinking, as key systems thinking skills. Senge (1990) conducted a study entitled "Systems thinking "that provided methods of implementing systems thinking. He introduced the lack of proper understanding of the issue, lack of understanding of the integrity issue, understanding of the relations between variables, and lack of complexity of the issue as the challenges of systems thinking. Baron (2014) mentioned the barriers to learning in a study entitled "Overcoming barriers in learning cybernetic science". He introduced the following items as barriers to learning: dealing with a single solution and copying from others, using different tools, not the same tool, clearing the issues, not solving them, superficial thinking, lack of understanding the intercultural differences, and inaccuracy in listening and seeing well. Trochim et al. (2006) conducted a study entitled "Practical challenges of systems thinking and modeling in public health". Their goal was to identify and describe the executive challenges of systems thinking in the field of public health. Schuler et al. (2018) conducted a study entitled "Systems thinking within the scope of education for sustainable development – a heuristic competency model as a basis for teacher education". They introduced systems thinking as the main competence in the field of education for sustainable development (ESD) because it helps students understand the complexity and dynamics of natural and social, and economic systems. They created a competency model that distinguishes the four dimensions of systems thinking in ESD.

Beasley (2012) conducted a study entitled "The barriers to systems thinking". "Systems thinking is a prerequisite for effective systems engineering and is one of the most difficult elements to identify, develop, and use."; he said. Based on the experience of implementing effective and explicit systems engineering in Rolls-Royce, the author offered ideas for overcoming barriers. He also stated that systems thinking should be integrated with the processes and knowledge, roles within the organization, and effective leadership that supports the implementation of systems thinking. Binesh (2011) conducted a study entitled "The barriers to systems thinking". He, in his study, described the components of systems thinking. He also investigated the most important barriers to systems thinking in partial aspects, i.e., focusing on events, projection, the trap of dual thinking, stereotype, formative thinking, attention to signs instead of causes, analytical thinking, and attention to quantity. York et al. (2019) investigated applications of Systems Thinking in STEM Education. They found that systems thinking approaches have generally been used in life sciences, earth sciences, and engineering but not in the physical or mathematical sciences. They realized that the primary emphasis of peer-reviewed publications was on the development of students rather than teachers' systems thinking abilities. Berry et al. (2018) used systems thinking to describe relationships to modern epidemiology and propose adopting a systems approach to remedy present limitations. They outlined existing thoughts about climate change and mental health and discussed vital limitations in modern epidemiology to evaluate this issue. Moscardo (2021) used systems thinking to improve tourism and hospitality. He demonstrated how the systems thinking approach could be implemented to boost both the relevance of and theoretical development in tourism and hospitality research in sustainability. He also showed the power of taking the systems thinking approach to map out the research problem area. Kuo et al. (2020) introduced the concept of systems thinking to enhance the performance of the prediction models. They found that introducing the concept of systems thinking resulted in significant power of the models, indicating that interdisciplinary efforts could potentially improve prediction performance. In their case study, they demonstrated that machine learning algorithms utilizing the systems knowledge could significantly improve the performance of waiting time prediction.

A summary of the research background is given in Table 3:

Table 3. Studies related to the barriers and challenges in systems thinking

code	Research Topic	Author
1	Theories and challenges for systems thinking in practice	Basile and Caputo (2017)
2	Cultural barriers in growing entrepreneurship: A study in singapore	Low, (2005)
3	Assessing systems thinking: a tool to measure complex reasoning through ill-structured problems	Jacob and Warschauer., (2018)
4	An introduction to systems thinking	Richmond and Peterson (2001)
5	The art and practice of the learning organization	Senge (1990)
6	11 laws of systems thinking from peter senge's perspective	Norouzi (2017)
7	Factors affecting the successful implementation of high-performance teams	Castka et al., (2001)
8	Overcoming barriers in learning cybernetic science	Baron (2014)
9	Practical challenges of systems thinking and modeling in public health	Trochim et al., (2006)
10	Systems thinking within the scope of education for sustainable development – a heuristic competence model as a basis for teacher education	Schuler et al., (2018)
11	The barriers to systems thinking	Beasley (2012)
12	Barriers to systems thinking	Binesh (2011)
13	Applications of systems thinking in stem education	York et al., (2019)
14	The case for systems thinking about climate change and mental health	Berry et al., (2018)
15	A systems thinking approach to understanding the challenges of achieving the circular economy	Iacovidou et al., (2021)
16	Using systems thinking to improve tourism and hospitality research quality and relevance: a critical review and conceptual analysis	Moscardo, (2021)
17	An integrated approach of machine learning and systems thinking for waiting time prediction in an emergency department	Kuo et al., (2020)

3.1. Summary of research background

A review of the existing literature on barriers to implementing systems thinking in the world shows that most previous studies have not directly addressed the barriers to implementing systems thinking. (Such as the Secular, 2017 and Richmond and Peterson, 2001). Instead, most studies have addressed the applications of systems thinking in real-world problems, such as Kuo et al. (2020). None of the researchers has collected and examined the barriers to implementing systems thinking in detail, and each has pointed out some of the barriers in a piecemeal manner. (Such as Binesh, 2011 and Beasley, 2012).

Furthermore, the barriers to implementing systems thinking in Iran have not been completely and comprehensively done so far, and only Binesh (2011) has pointed to a limited number of barriers and explained them. No previous research has analyzed the relationship between these barriers and interpretive structural modeling. Therefore, in this study, to identify and assess the barriers to systems thinking as our main contribution, the research in this field from 1990 to the end of 2021 was examined, and the mentioned barriers in them were collected. As a result, it can be said that the present study is innovative in terms of the method and the comprehensive view it applies.

4. Research methodology

This study aimed to investigate the barriers to systems thinking implementation and conduct a systematic model with ISM. A review of the literature was used to identify the barriers. Then, the ISM model was adopted to prioritize the identified barriers. After reviewing the literature and a comprehensive study of its content, 64 major barriers to implementing systems thinking in the first step have been identified. Then, a questionnaire was used to integrate, summarize, and classify the indicators. Also, the opinions of professional and academic experts have been considered to identify and determine the relationship between the identified barriers to the implementation of systems thinking for the development of interpretive structural models (ISM). The approach of this research is exploratory.

In the present study, experts were selected using purposive sampling. Out of different managers and experts in systems thinking in Iran, 8 experts were chosen in order to employ the ISM method and examined the structural relationships between the identified variables.

4.1. Steps of the research process

The steps of conducting research are as follows:

- Extracting indicators from the research literature
- Determining overlaps and merging indicators
- Classification of indicators
- A structural relationship is constructed among the identified variables
- A structural self-interaction matrix (SSIM) is formed for the variables, reflecting the doublet relationships of the variables of the structure under consideration. (See Table 4)
- A reachability matrix is formed from the SSIM, then scanned for transitivity. (See Table 5)
- In this step, the formed reachability matrix is further subdivided into 2 levels. (See Table 6 and 7 Iteration i-ii)
- In this step from the reachability matrix, a direct graph is drawn, and the transistive assocaion are detached. (see Figure 1)

In the following subsections, we will explain each in detail.

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4.1.1. Extracting indicators from the research literature

In the first stage, the library study method was used to be fully acquainted with the subject, study the research background, and determine the barriers to implementing systems thinking. In order to identify the barriers to systems thinking, related works from 1990 to the end of 2021 were reviewed, barriers were extracted from the previous studies, and their importance in the systems thinking literature was investigated. The number of studies conducted in this field is very limited, and most researchers have not directly mentioned the barriers. At this stage, the content was entirely studied to extract the largest number of indicators. Even the indirectly mentioned cases in the articles were studied and extracted. Finally, a comprehensive list of dimensions and barriers was prepared, and 64 factors (barriers) were identified.

4.1.2. Determining overlaps, merging indicators, and classifying indicators

In the second stage, by sending a questionnaire to 8 academic experts with relevant education and experience, we localize and finalize the factors identified in the first stage. At this stage, after discussion by the expert team, some indicators were merged, and some overlaps were removed. Finally, all indicators were summarized and finalized in 25 indicators. In Table 2, the names of the indicators, their operational definitions, and the sources from which these indicators are extracted are mentioned. (Based on the codes in Table 1)

In the next step, in order to reduce and summarize the indicators for pairwise comparisons, using the opinions of the expert team, 25 barriers were classified into 7 categories, and these 7 categories were used as input to the next step. The findings of this stage are combined with the previous stage and are listed in Table 2.

Table 2. Operational definitions of dimensions

Code	Operational definition	Name	Category	Row
4	Management based on old schools such as Classic, Taylor, Weber, etc.	Traditional management	Organizational	1
4, 12	Existence of multifaceted thinking, from a multidisciplinary and multidimensional perspective on a subject, development of a mission, and integrated vision between different departments and layers (neighborhood, regional, national and international)	Lack of interdisciplinary and transregional thinking	Cultural	2
4,14,15	People's mental frameworks in their learning process	Stereotyped thinking	Mental	3
5,7	The skill by which a person acquires new thoughts or relationships with the help of problem-solving and decision making and finds the power to discover and choose new solutions.	Lack of creative thinking and soft skills	Mental	4
7,9,15	Linear consideration of cause and effect relationships	Linear thinking	Mental	5
8	Lack of proper understanding of the issue	Lack of proper understanding of the issue	Mental	6
8,14	Lack of understanding of the complexity of the problem due to the existence of complex and large organizations	Lack of understanding of the complexity of the problem	Mental	7
8	Lack of understanding of the integrity of the problem and understanding of the relationships between variables	Lack of understanding of the integrity of the problem	Mental	8
9,11	Controlling the effects of a problem instead of solving the root of the problem is simplistic	Superficial thinking	Personality	9
9,12,14	Searching for the Most Available Cause, Looking for a Quick and Efficient Solution Instead of Finding a Sustainable Solution, Ignoring Delay	Short-sighted thinking	Personality	10
4,9,15	Divide the system and try to analyze the parts independently	Analytical and mechanical thinking	Mental	11
9,15	Negativity and blaming environmental conditions	Projecting	Personality	12
4,9,10, 11,12,14	Barriers such as task-oriented organizational structure, individual performance appraisal, lack of systems thinking in evaluation indicators, lack of team culture in the organization, lack of encouragement and motivation of systems thinking, lack of necessary infrastructure and resources, lack of systems thinking in macro goals and programs, policies and bureaucracy	Organizational barriers	Organizational	13
4,10,12 ,13,14	Lack of sufficient knowledge to solve problems among team members, lack of training in systems thinking, training based on simple examples and lack of equipping people with complex techniques to deal with real problems	Lack of sufficient knowledge and skills	Educational	14
11	Clear problems instead of solving them	Clear the problem	Personality	15
11	People do not pay attention to listening and seeing carefully	Inaccuracy in what is heard and seen	Personality	16

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Code	Operational definition	Name	Category	Row
12	Develop methods and tools that encourage a systems approach, identify and disseminate examples of "best practices" or "best practices" in systems thinking	Lack of methods and tools of systems thinking	Educational	17
12	Lack of financial resources for its inclusion and further training	Lack of financial resources	Financial	18
12	Lack of support from the authorities for team building and the pervasiveness of systems thinking	Lack of official support for systems thinking	Organizational	19
14	Use methods to prove the value and identity of systems thinking	Lack of proof of the value of systems thinking	Cultural	20
4,14	Barriers such as not allocating enough time to get more information, insufficient information, lack of access to information, thinking about the size of previous uncertainties, and seeking to recognize new uncertainties, dispersion, and large and erratic amount of information in the new age	Information barriers	Informational	21
14,15	With the instability of problems and their constant change, the human mind is not able to understand the dynamics of the problem and process all information simultaneously. Focusing on events prevents us from finding the pattern of long-term change behind events.	Difficulty understanding the dynamics of the problem	Mental	22
14	The nature of program and project management tends to progress quickly and according to plan and does not allow for a proper understanding of the system	The linear nature of tracking project progress	Organizational	23
14	Standardize and share problem-solving with a dynamic system approach	Lack of standards for solving problems	Educational	24
15	Paying attention only to numbers and figures, paying attention to size or numbers, is a category that, in Russell Ackoff, is related to "growth", not "development", while systems thinking is a developmentalist thinking.	Paying too much attention to the quantity	Educational	25

4.1.3. Preparation and completion of Interpretive Structural Modelling (ISM) questionnaire for final indicators

In the third stage, the pairwise comparison questionnaire was used to extract experts' opinions in identifying and analyzing the relationships between barriers in the form of interpretive structural modeling. For this research, the ISM method has been used. This method is an interactive learning process in which a set of different interrelated elements are structured in a comprehensive systematic model (Warfield, 1974). This methodology helps to create and direct complex relationships between the elements of a system (Faisal et al., 2006). One of the main areas of this method is that the elements that have a greater impact on other elements in a system are always more important. The model obtained using this methodology shows the structure of a complex problem or topic, a system or field of study that is a carefully designed model (Faisal et al., 2006).

As a result, we can say that interpretive structural modeling not only provides insight into the relationships between the various elements of a system but also provides a structure based on the importance or impact of the elements on each other and displays a visual representation. This is an interpretive method because the judgment of a group of people determines whether there are relationships between elements. This is a structural method because the basis of relationships is a global structure derived from a complex set of variables.

4.1.4. Structural Self-Interactive Matrix Formation (SSIM)

In this step, the experts consider the criteria in pairs and respond to the pair comparisons based on the following. That is, in each comparison, the two criteria use the letters V, A, X, O based on the following definitions.

V: The factor of row i causes the factor of column j to be realized.

A: The factor of column j causes the factor of row i to be realized.

X: Both row and column factors cause each other to be realized (factors i and j have a two-way relationship).

O: There is no relationship between the row and column factor.

Table 3 shows the results of expert opinions and pairwise comparisons.

Table 3. Structural self-interaction Matrix (SSIM)

Information	**Financial**	**Educational**	**Personality**	**Mental**	**Cultural**	**Organizational**	
V	**V**	**X**	**X**	**O**	**A**	**-**	Organizational
V	**X**	**X**	**X**	**O**	**-**	**V**	Cultural
A	**0**	**A**	**X**	**-**	**O**	**O**	Mental
V	**O**	**A**	**-**	**X**	**X**	**X**	Personality
V	**A**	**-**	**V**	**V**	**X**	**X**	Educational
O	**-**	**V**	**O**	**O**	**X**	**A**	Financial
-	**O**	**A**	**A**	**V**	**A**	**A**	Informational

4.1.5. Obtaining the initial achievement matrix

This matrix is obtained by converting the symbols of the SSIM matrix to numbers zero and one based on the initial access matrix.The four symbols used to indicate the direction of the i and j relationship are as follows:

- V: variable i leads to variable j.
- A: variable j leads to the variable i.
- X : a bidirectional relationship (from i to j and from j to i)
- O: no relationship between the variables.

Table 4 shows the results of this step.

Table 4. translation SSIM to binary matrix

Information	Financial	Educational	Personality	Mental	Cultural	Organizational	
1	1	1	1	0	0		Organizational
1	1	1	1	0		1	Cultural
0	0	0	1		0	0	Mental
1	0	0		1	1	1	Personality
1	0		1	1	1	1	Educational
0		1	0	0	1	0	Financial
	0	0	0	1	0	0	Informational

4.1.6. Matching the achievement matrix

Once the initial access matrix is obtained, the final access matrix is obtained by considering the exponential relations between the criteria. In the initial achievement matrix, the rule must be checked that if criterion A is related to criterion B and criterion B is related to criterion C, then criterion A must also be related to C. The numbers marked with a* in Table 5 are obtained by diffusion relationship.

Table 5. Final Reachability matrix

Information	Financial	Educational	Personality	Mental	Cultural	Organizational	
1	1	1	1	1*	1*	-	Organizational
1	1	1	1	1*	-	1	Cultural
0	0	0	1	-	1*	1*	Mental
1	1*	1*	-	1	1	1	Personality
1	1*	-	1	1	1	1	Educational
1*	-	1	1*	1*	1	1*	Financial
-	0	0	0	1	1*	1*	Informational

4.1.7. Determining the level of variables

In this step, the set of input criteria (prerequisite-initial set) and output (achievement) for each criterion are calculated, and then the common factors are identified. In this step, the criterion has the highest ISM level that the output set (achievement) is equal to the common set. After identifying these variables, their rows and columns are removed from the table, and the operation is repeated on the other criteria. The results of this step are given in Table 6 and 7.

Table 6. Iteration

Level	Intersection set	Antecedent Set	Reachability Set	Criterion
1	2,3,4,5,6,7	2,3,4,5,6,7	2,3,4,5,6,7	Organizational
1	1,3,4,5,6,7	1,3,4,5,6,7	1,3,4,5,6,7	Cultural
	1,2,4	1,2,4,5,6,7	1,2,4	Mental
1	1,2,3,5,6,7	1,2,3,5,6,7	1,2,3,5,6,7	Personality
1	1,2,3,4,6,7	1,2,3,4,6,7	1,2,3,4,6,7	Educational
1	1,2,3,4,5,7	1,2,3,4,5,7	1,2,3,4,5,7	Financial
	1,2	1,2,4,5,6	1,2,3	Informational

Table 7. Iteration ii

Level	Intersection set	Antecedent Set	Reachability Set	Criterion
2	1,2,4	1,2,4,5,6,7	1,2,4	Mental
3	1,2	1,2,4,5,6,7	1,2,3	Informational

4.2. Mapping network interactions

In this step, according to the levels of criteria in ISM and the relationships between them, a network of interactions is created. The network is shown in Figure 1.

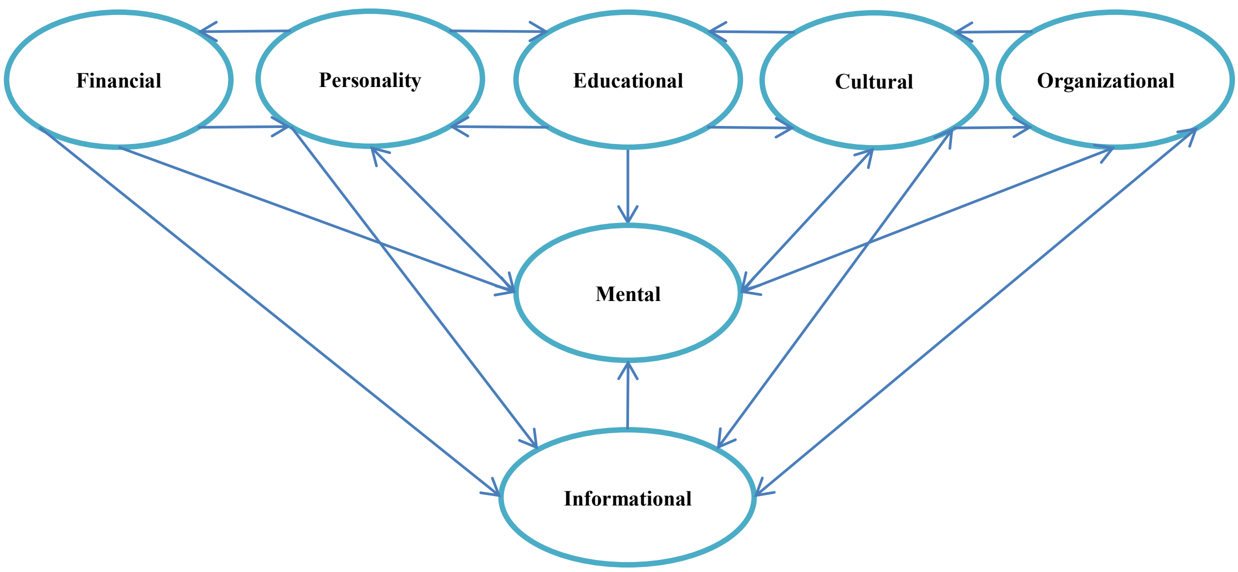

Figure 1. The relationships between criteria

5. Discussion and conclusion

In the present study, first, the barriers to the implementation of systems thinking in organizations were identified and finalized. Then, using the interpretive structural modeling technique, their relationships and leveling were performed. It is interesting to note that some of the variables, such as "cultural barriers", have been indicated directly by some authors like Baron (2014), but some of them are mentioned indirectly (Beasley, 2012; Binesh, 2011; Trochim et al. 2006). According to the hierarchical conceptual model of the ISM method and Tables 7 and 8, "organizational", "cultural", "personality", "educational", and "financial" barriers act as the most important criteria of this model and removing barriers to the implementation of systems thinking should start from these barriers and extends to other barriers at lower levels. The informational barrier has the most impact and the least impact on other factors in the model. Therefore, by removing other barriers, this barrier will be removed to a large extent on its own. Mental barriers are in the middle of the model and are not very effective. Furthermore, by examining the following factors in this category, it can be understood that these factors cannot be eliminated directly to a large extent or that change in them is hardly possible. In conclusion, it is an interesting fact that all previous studies have not investigated systems thinking barriers completely and have not had a systematic view and review of them. Therefore, it is clear that this study has a contribution and innovation in investigating systems thinking barriers and can lead to organizational improvement totally, through systems thinking implementation.

One of the important points that can be deduced from the conceptual model between factors is that almost all factors have two-way relations with each other; that is, they are strongly interdependent. Change in one leads to change in other factors; in other words, it can be said that improvement in each category leads to the exponential growth and development of systems thinking in organizations.

According to the results, suggestions can be made to organizations in Iran. The results showed that 5 categories of factors: "organizational", "cultural", "personality", "educational", and "financial" are among the most important factors, and organizations' funds should be allocated to education, personality, and cultural dimensions of individuals in the organization that affect and improve all 5 factors simultaneously.

Organizations can clearly understand what needs to be improved by examining these sub-factors. For example, "lack of sufficient knowledge and skills", "lack of methods and tools of systems thinking", "lack of standards for problem-solving", and "excessive attention to quantity", which fall into the category of educational factors, should be the agenda of the training department of all organizations. Of course, the education ministry and higher education departments must simultaneously pay attention to these indicators in their educational content and include them in education from primary to university. Also, due to the unfamiliarity of some industry workers with the concept of systems thinking, it is suggested that seminars, scientific conferences, and workshops in the field of systems thinking to be held by the organizations themselves or by the Industrial Towns Company. In addition, industrial consulting units should be set up by industrial estates.

Considering the importance and the first level of financial factor, it is suggested that organizations consider special and separate budgets for training and evaluation based on systems thinking and take steps to improve and develop the level of systems thinking in organizations. Organizational factors, such as traditional management, linear nature of project progress, lack of support from officials for systems thinking, and other organizational factors show that there is a need for managers and senior officials to pay more attention to the dimensions of systems thinking and its implementation. They should discard their old views and update their management style with new ones that are fundamental for developing systems thinking. Moreover, to influence individuals' personality issues, they can be given correct and principled training in this field. Due to the relationship between this factor and other factors, changes in individuals' intellectual style and personality lead to changes in cultural and organizational factors, becoming mental, information, and so on.

Cultural factors, such as "lack of interdisciplinary and transregional thinking" and "failure to prove the value of systems thinking culture", can also be reinforced by propaganda and culture development. It is necessary to influence the people of the society in this field and penetrate their culture to raise their perspective from the level of the individual to the team, the society, and beyond.

Given that each of the investigated factors can be different from organization to organization and depending on the type of organization (production or service), some factors may be more prominent in this category of organizations; it is recommended that in the next studies, one focus on different organizations as case studies and extract implementation barriers in each organization separately. These barriers can also be examined in different industries, and the results are compared. Using methods such as structural equations is recommended to statistically validate the model presented in this study. In fact, the use of structural equations, in this case, plays a complementary role to the ISM model. Other factor analysis approaches are also suggested to be used to identify categories in future studies. Other methods, such as DEMATEL, can also be used to analyze the relationship between factors, and the results can be compared with this method. Also, it is suggested that this model be combined with the QFD model.

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Guide for Authors

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