Evaluating the Impact of Managerial Decisions on Production Costs Using Agent-Based Modeling Based on the Theory of Constraints

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Abstract

The purpose of the present study was to design an agent-based model to evaluate the impact of internal and external organizational decisions on the cost of industrial production based on the Theory of Constraints. The research methodology is applied in terms of purpose and falls within the domain of exploratory quantitative and field studies. The statistical population of this research includes all experts and informants in the field of industrial production costs, who were selected using the snowball sampling method. In this study, 25 experts were chosen as the sample, and data collection was conducted using corporate databases to examine the research objectives, focusing on industrial production and pricing data. For data analysis, three methods were employed: thematic analysis, the Delphi technique, and agent-based modeling. AnyLogic software was used to perform simulations for validating the model. The findings revealed that two types of improvement policies were examined in this study. The impact of production policies on product demand and pricing to enhance the competitiveness of production costs. The impact of capacity planning policies. It is noteworthy that this issue was designed with an agent-based modeling approach, and an analysis of the research model's behavior indicates that the implementation of production policies increases the rate of product costs. This aligns with competitive activities among companies and fosters the formation of favorable pricing in customers' perceptions.

Keywords: *Agent-based modeling, managerial decisions, Theory of Constraints, production costs*.

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1. Introduction

One of the key pieces of information in organizations, especially in production sectors, is the calculation of production costs. Companies with lower production costs compared to their competitors achieve higher profitability [1]. Therefore, production costs are a critical and significant topic in the management of manufacturing organizations [2]. Various characteristics can influence the calculation of production costs, with one of the most important being the decision-making variable [3, 4]. According to Kahneman (2010), decision-making occurs in two domains: internal organizational decision-making and external organizational decision-making [5, 6].

Internal organizational decision-making refers to all measures that can be implemented by senior managers, while external organizational decision-making is carried out by managers or entities outside the organization that are likely to impact the organization's activities. In recent years, many manufacturing companies worldwide have sought to sustain their presence in competitive environments by transforming into organizations that aim to implement cost leadership strategies in production. These strategies are intended to reduce costs for both the organization and its customers [7]. Additionally, traditional costing systems have failed to provide accurate, timely, and reliable information for managerial decision-making in areas such as pricing. As a result, innovative methods have been introduced [8].

One of the most significant challenges faced by industrial companies is deciding on the optimal product mix. Given resource constraints, product combinations must be selected to maximize benefits. Various methods have been proposed to address this issue. One such approach is the Theory of Constraints, which provides valuable information for decision-making [9, 10].

The review of previous studies highlights the significance of utilizing methodologies such as agent-based modeling and the Theory of Constraints (TOC) for pricing and production management in industrial settings. Javadianpour et al. (2019) explored the application of ABC and TOC models in product pricing, revealing their complementary roles in sales decision-making [11]. Houshmand (2019) examined TOC in production planning and management, identifying bottlenecks in a tile manufacturing company and developing production plans using sensitivity analysis [12]. Esmaeili (2015) employed TOC to determine optimal product combinations under variable production priorities, using mathematical modeling and comparison with actual production outcomes [13]. Eskandari (2014) demonstrated how TOC thinking processes could identify and address bottlenecks in an elevator component manufacturing facility [14]. Hasanzadeh (2013) integrated TOC thinking processes with QFD to create a systemic approach applicable to production environments and broader policy domains [15]. Ghazanfari (2011) used TOC thinking processes to identify root causes of organizational inefficiencies in a case study, employing methodologies like current reality tree and three-cloud analysis [16]. Pacheco et al. (2018) underscored the importance of bottleneck identification for effective production changes based on TOC principles. Utko (2018) emphasized TOC's focus on enhancing productivity by managing constraints rather than traditional cost or inventory reduction methods [7]. Trojanowska (2017) detailed TOC's systemic approach, highlighting its premise that every system has constraints that, if managed, unlock growth potential [10]. Finally, Gundogar et al. (2016) illustrated TOC’s iterative process of identifying and overcoming bottlenecks for system-wide optimization [17]. The consensus across these studies is the vital role of agent-based modeling in production and pricing environments [18-20]. In recent years, agent-based modeling has emerged as an effective quantitative research methodology, allowing researchers to create, analyze, and test systems with interacting agents in a defined environment. This research aims to design an agent-based model to simultaneously evaluate internal and external organizational decisions' impacts on industrial product pricing, incorporating TOC principles, a novel approach in academic research within the country.

TOC can be considered a novel systematic perspective in the thought process. Its introduction and focus on organizational achievement created a new paradigm that changed the way organizations approach productivity and improvement strategies, increasing the likelihood of effective and impactful changes. One of the most flexible modeling methods is agent-based modeling. This approach is named as such because agents play a fundamental role in the model. In this type of modeling, each agent in the real world is represented as an autonomous and decision-making entity called an agent model. Each agent consists of various components to perceive the environment, analyze it, and ultimately take action [19]. Thus, the primary issue in this study is designing and implementing an innovative agent-based model tailored to the localized process of estimating production costs in Iran. The model must not only align with known conditions but also possess the necessary flexibility for application in industrial production environments.

2. Methodology

This research, considering its objectives, is classified as applied research. In terms of the research process, it falls within the domain of exploratory quantitative and field studies. The statistical population of the study consisted of experts and informants specializing in the cost of industrially produced goods, selected using the snowball sampling method. In total, 25 participants were identified as the final sample. Data were collected from corporate databases to analyze the study's objectives, focusing on industrial production data and pricing. Data analysis was performed using three methods: thematic analysis, the Delphi technique, and agent-based modeling. AnyLogic software was employed to simulate and validate the model.

As mentioned, thematic analysis was used to derive the dimensions of the model. Through interviews conducted with experts (35 participants in the qualitative section), endogenous and exogenous factors, along with sub-factors, were identified under two main categories. In this context, each concept was first developed and subsequently assigned a central code corresponding to the subcategory of each identified category. These were then categorized based on their respective topics, which could effectively assess the impact of internal and external organizational decisions on industrial production costs using the Theory of Constraints.

To further refine the model's dimensions, thematic analysis was applied, identifying 31 factors through a review of literature, texts, and expert opinions. The Delphi approach was used to achieve consensus among experts.

In the third round of Delphi, Kendall's coefficient of agreement for this round's responses was determined to be 0.944, indicating an increased level of agreement among experts. Since there was minimal difference between this round's coefficient and the second round's, it was concluded that the experts' consensus coefficient is 0.94.

3. Findings

Table 1. Delphi Technique Results

Main Factors	Sub-Factors	Number of Responses	Mean of Responses	Standard Deviation
Internal Factors	Marketing	25	3.56	0.45
	Advertising	25	3.43	0.34
	Distribution & Sales	25	3.55	0.65
	Transportation	25	3.65	0.67
	Human Resources	25	4.23	0.71
	Manufacturing Overhead	25	4.11	0.65
	Investment	25	4.32	0.40
	Profit Level	25	3.98	0.74
	Sales Volume	25	3.45	0.47
	Pricing	25	3.65	0.54
	Depreciation Costs	25	3.46	0.61
	Production Capacity	25	3.21	0.48
	Energy Consumption	25	3.78	0.46
	Bulk Discounts	25	3.23	0.43
External Factors	Technology Level	25	3.55	0.67
	Inflation	25	3.24	0.43
	Taxes & Duties	25	3.56	0.46
	Market Competition	25	3.44	0.45
	Exchange Rate	25	4.21	0.65
	Interest Rate	25	4.34	0.74
	Licensing Costs	25	3.54	0.89

Regulations	25	3.56	0.58
Import & Export Levels	25	3.21	0.73
Market Demand	25	3.67	0.83
Energy Carrier Prices	25	4.32	0.74
Raw Material Prices	25	4.34	0.93
Market Nature	25	3.54	0.64
Competitor Prices	25	3.23	0.71
Market Boom or Recession	25	3.54	0.65
Price Elasticity	25	3.78	0.45
Substitute Products	25	3.23	0.38

Agent-based modeling, one of the most flexible modeling methods, derives its name from the fundamental role of agents in the model. In this approach, each real-world agent is represented as an autonomous and decision-making entity called an agent model. These agents are equipped with various components for perceiving their environment, analyzing it, and taking action.

Agent-based modeling aims to simulate real-world decision-making processes using similar agents. Individuals, companies, projects, assets, vehicles, cities, and products can all be defined as agents in the model. The behavior of each agent is mapped in the model, and upon execution, agents operate independently within their defined environment based on predefined behaviors.

Agent-based modeling is an effective method for simulating complex economic, social, and general systems. It complements and extends econometric methods by combining system interactions and adaptability. Since it allows for the study of individual units, it incorporates heterogeneity among system agents. Through simple decision-making rules, complex business phenomena can be described.

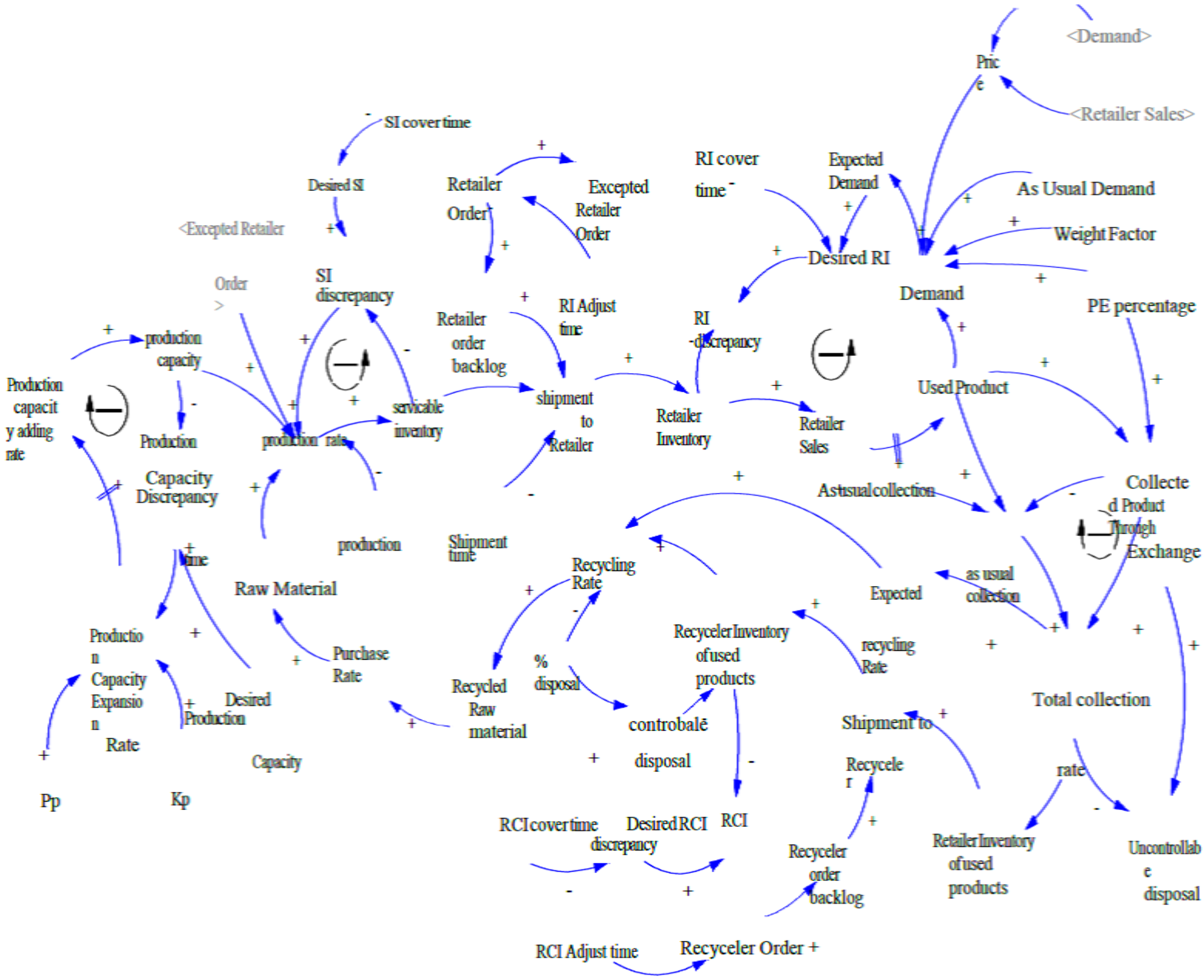

Figure 1. Causal Loop Diagram

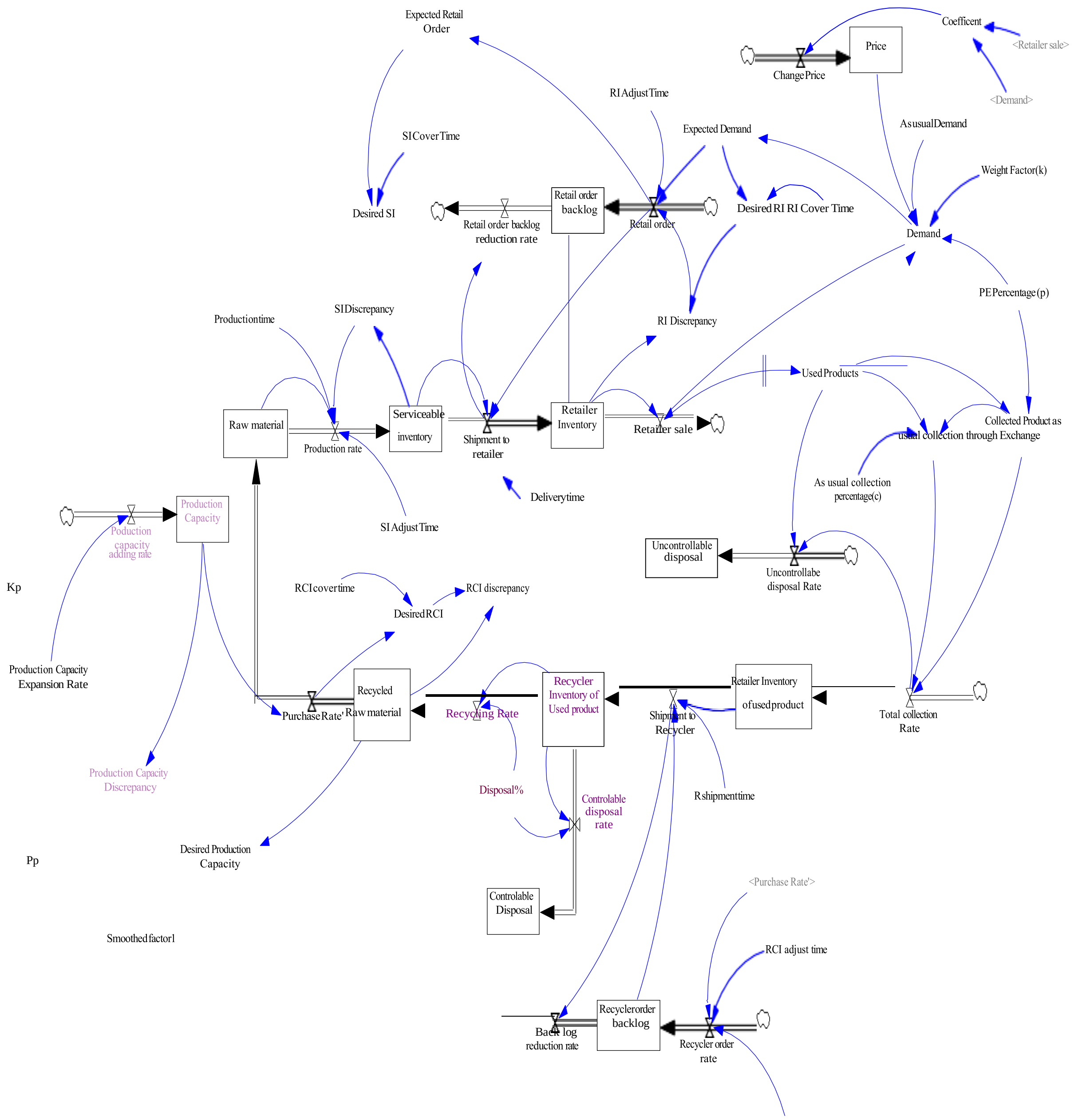

Figure 2. Stock and Flow Diagram

The impact of production policies on demand and pricing is illustrated in Figure 1. As shown in Figure 1, implementing these policies increases product demand. The production policy within the model, represented in Figure 1, is formulated by the following equations:

1. Collected_Product_through_Exchange = p * Used_Products
2. As_Usual_Collection = (Used_Product - Collected_Product_through_Exchange) * c
3. Total_Collection_Rate = Collected_Product_through_Exchange + As_Usual_Collection
4. Demand = Demand + k * (p * Used_Products)

In these equations, "p" represents the percentage of product production (PE). The pricing rate without the production policy is denoted by "c", while "k" is a weighting factor that helps define the relationship between demand and PE. The values of "k" and "c" vary between companies and products. If k = 0, PE has no effect on demand for new products. If k > 0, PE influences demand.

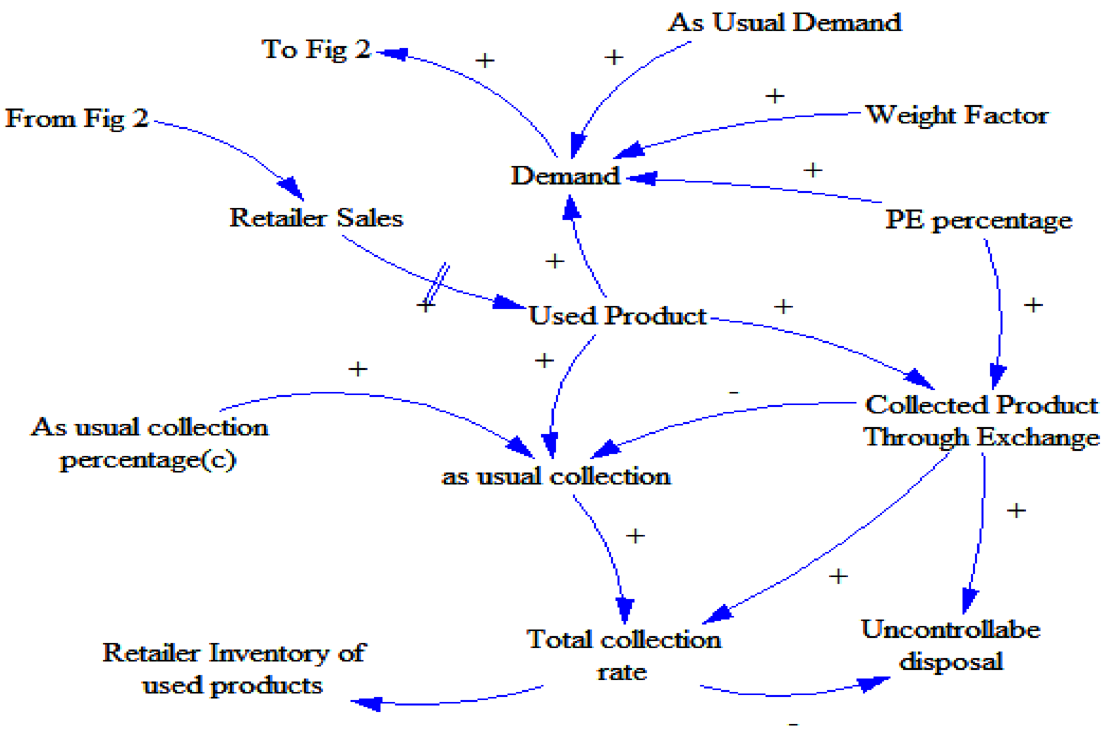

Figure 3. Causal Loop Diagram for Demand, Product Production, and Pricing

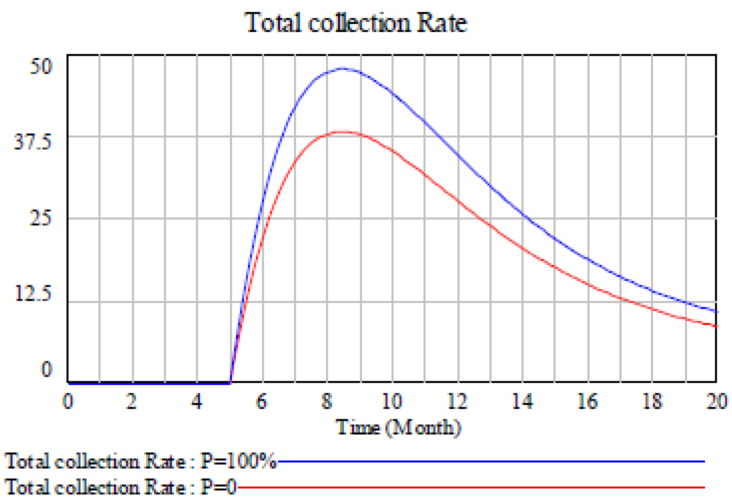

Figure 4. Impact of PE on Pricing

Production capacity is reviewed every Pp time unit, and decisions are made regarding investment in production capacity. The review period typically depends on the product life cycle and operational production costs, as analyzed in this model.

The rate of production capacity expansion is determined by the difference between the desired production capacity and the actual production. This difference is set to converge towards the desired level. The production capacity expansion rate in each period is positive and an integer multiple of Pp. This rate is modeled using a pulse function, where each pulse amount is a proportion of the production capacity difference in a time period multiplied by the Kp parameter.

In the leading capacity strategy, additional capacity is accumulated to respond to sudden demand changes. The trailing capacity strategy delays demand and fully utilizes capacity, while the matching capacity strategy seeks to align demand and capacity over time. When Kp > 20, the leading capacity strategy is recommended, as simulation results indicate its effectiveness.

It is evident that there is a time lag between decisions to increase production capacity and their implementation, which is represented by the rate of capacity increase. This rate operates with a delay relative to the capacity expansion rate. Decision-makers can examine the effects of various policies by adjusting the above parameters. This model can also be used to simulate both increases and decreases in production capacity; however, this research focuses solely on increasing capacity, as the product's maturity phase is considered, with stable demand and product returns.

The impact of capacity planning policies on the model is illustrated in figures below. As seen, implementing capacity planning policies affects production capacity, with increased parameter values leading to higher capacity levels.

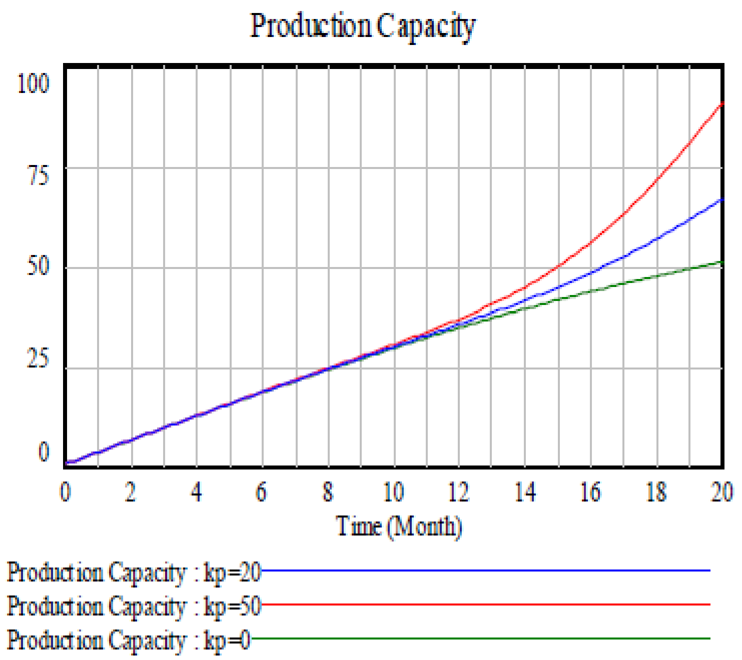

Figure 5. Impact of Kp on Production Capacity

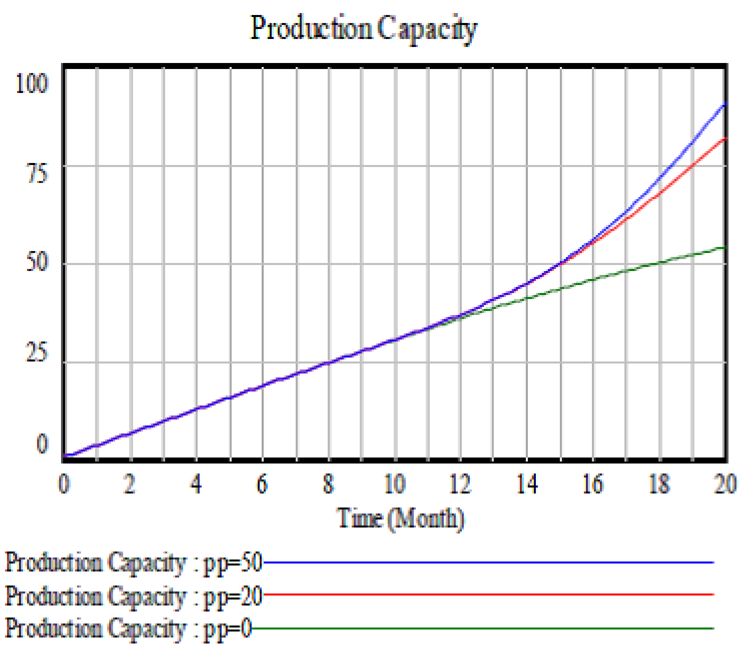

Figure 6. Impact of Pp on Production Capacity

As shown in the two graphs in Figure 7, as product prices in the market increase, customer demand decreases.

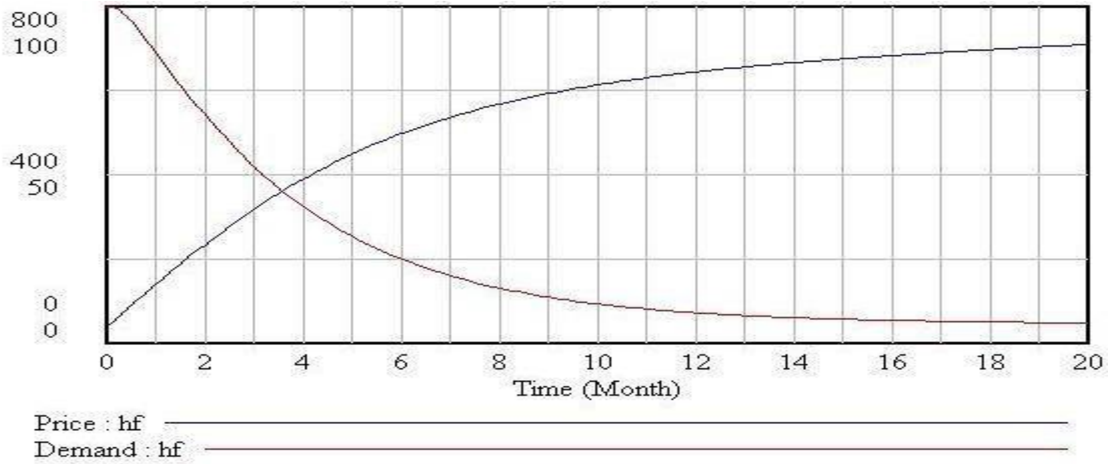

Figure 7. Price and Demand Graphs

As depicted in Figure 8, the production rate initially increases, causing raw material inventory to decrease. As production rates decline due to production planning policies, raw material inventory increases.

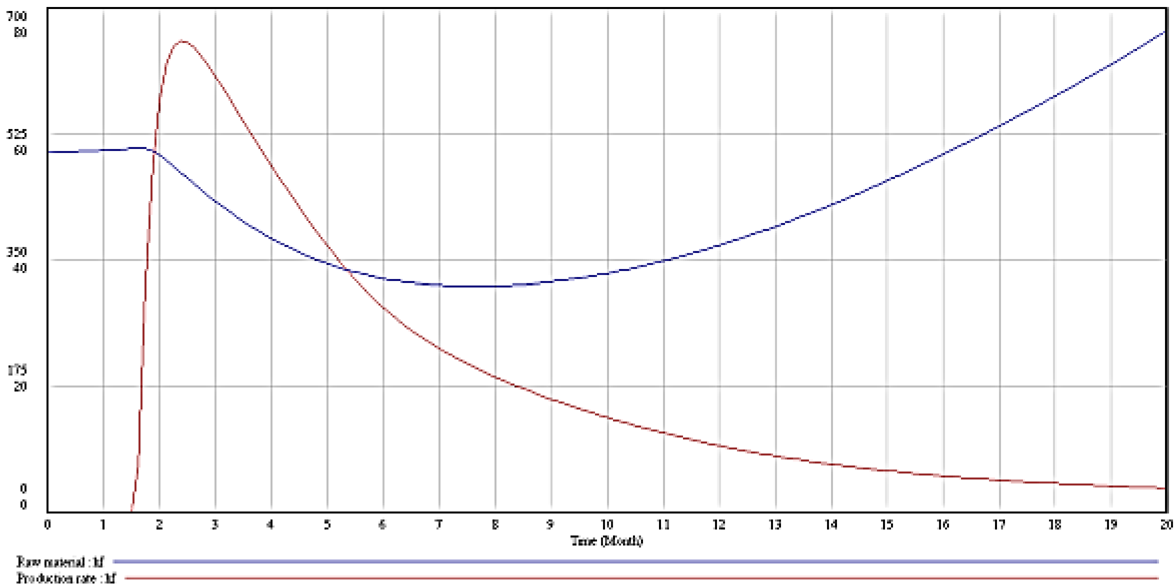

Figure 8. Raw Material Inventory and Production Rate Graphs

Two pricing methods—regular pricing and competitive pricing—were applied in the model. Comparing the two graphs in Figure 9 indicates that when prices are raised under regular pricing, the production volume of competitively priced products decreases.

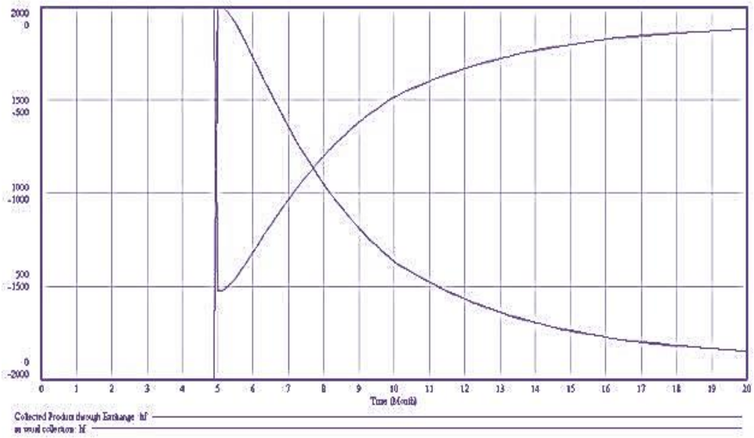

Figure 9. Comparison of As Usual Collection and Collected Product Through Exchange

To prevent excessive model complexity, the most significant factors influencing product costs were prioritized in the model. This effectively represents the system's status and interactions among its key components. Based on expert opinions regarding the relationships between variables, equations were formulated to analyze variable behaviors over three years with quarterly intervals.

Scenario 1: This scenario suggests focusing on reducing production capacity differences and raw material input levels in the short term to lower production costs. Managers should plan to reduce production capacity differences to 0.2 and raw material input levels to 0.4. Key variable behaviors after simulating Scenario 1 are shown in Figure 10.

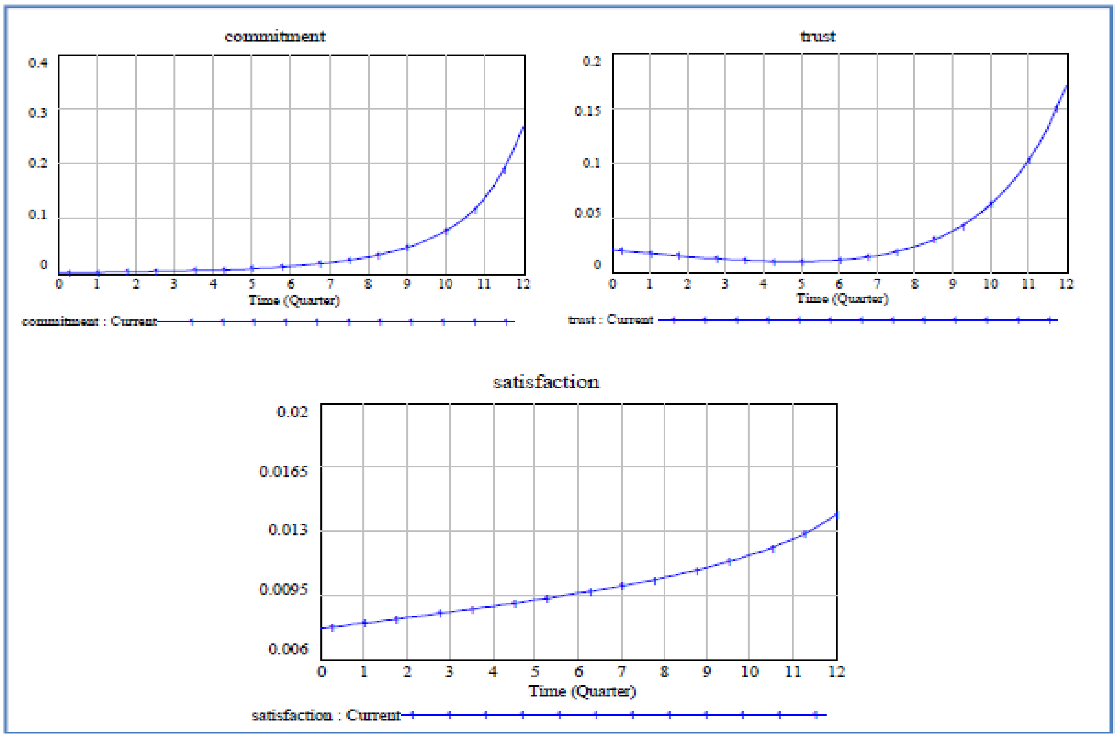

Figure 10. Results of Scenario 1 Simulation

Scenario 2: In addition to implementing Scenario 1, this scenario recommends that companies and suppliers resolve non-functional conflicts in their production systems in the long term, reducing them to 0.1. Key variable behaviors after simulating Scenario 2 are shown in Figure 11.

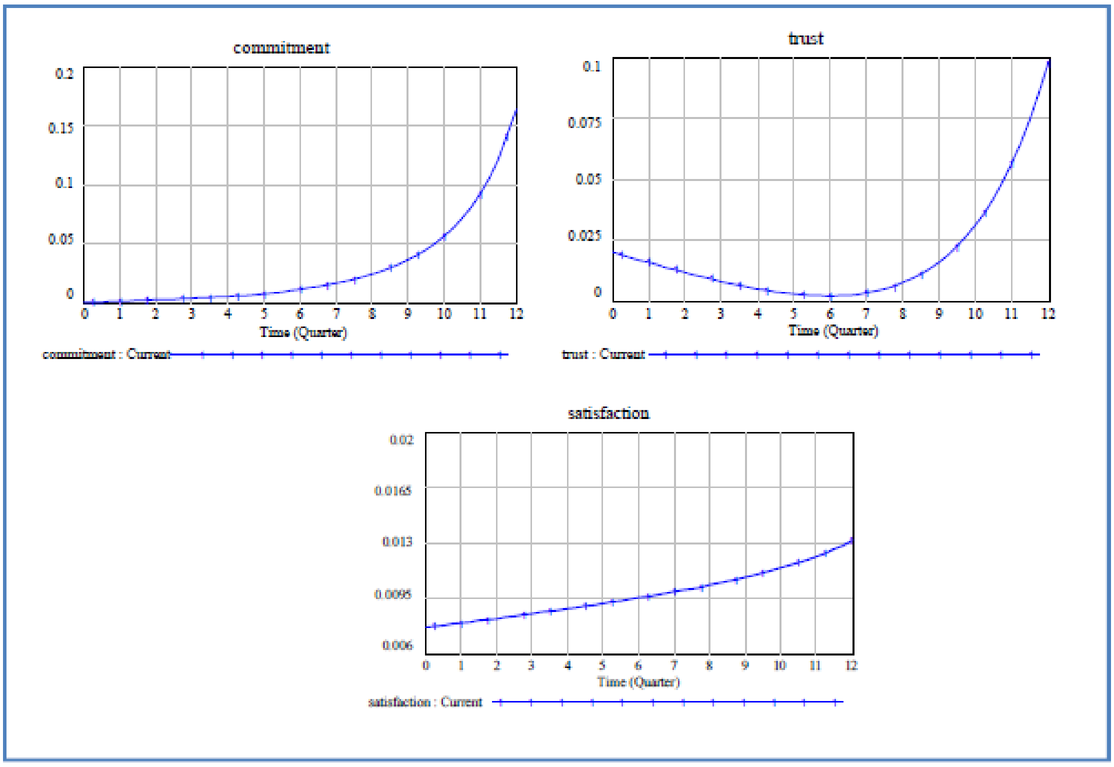

Figure 11. Results of Scenario 2 Simulation

Given the dynamic and fundamental relationship between internal and external organizational decisions and industrial production costs, it can be stated that the system possesses a dynamic strategic development structure. Therefore, companies should adopt a holistic approach rather than focusing solely on internal factors when making decisions. The presented model can significantly aid in achieving this goal and contribute to company success.

Scenario analysis results confirm that long-term returns are crucial in shaping key factors of production costs. Managers should evaluate long-term returns in short-term intervals to ensure sustained profitability. According to expert opinions, the most critical outcome of this research is the dynamic perspective it introduces regarding internal and external organizational decisions' influence on production costs and their interrelated variables. This concept transforms managerial perspectives on this complex and dynamic phenomenon.

Stress testing involves examining the model's stability by setting variables to extreme initial values. Placing key parameters at their minimum or maximum and testing model outputs is one validation method to assess sensitivity to changes. In this study, product orders were considered as an infinite scenario (lower limit), where simulation results indicated a cumulative value creation average of zero. At the upper limit (assuming optimal value creation), the model exhibited logical behavior, confirming its compliance with stress testing criteria.

In this method, simulation results were presented to 20 managers and experts from industrial and manufacturing companies for review. Participants were asked to provide feedback on the outcomes and suggest revisions. Experts compared simulation data with their experience of real-world IT-based business models. After incorporating expert opinions, simulation results were confirmed to align with real-world expectations. Based on these validations, the model was deemed reliable, allowing managers to confidently base decisions on its outcomes.

4. Discussion and Conclusion

Based on the findings, endogenous variables include marketing, advertising, distribution and sales, transportation, human resources, manufacturing overhead, investment, profit level, sales volume, pricing, depreciation costs, production capacity, energy consumption, and bulk discounts. Exogenous variables include technology level, inflation, taxes and duties, market competition, exchange rates, bank interest rates, potential licensing costs, regulatory requirements, import and export levels, market demand, energy carrier prices, raw material prices, market nature, competitor prices, market boom or recession, price elasticity, and substitute goods.

Cost accounting information is designed for managers. Since managers make decisions solely for their own organizations, there is no need for this information to be comparable with similar data from other organizations. Instead, the critical criterion is that the information should be relevant to the decisions managers make in a specific business environment, including the formulation of operational strategies. While cost accounting data is often utilized in financial accounting, its primary emphasis here is on its use by managers for decision-making. Accountants who process cost accounting information can add value by providing accurate data to decision-making managers. Regardless of whether the organization is a manufacturing company, bank, non-profit, government agency, or school, better decisions lead to improved performance. The cost accounting system is a result of managers' decisions and the environment they create within an organization.

This section focuses on modeling relationships between the indicators. In the current era, given global environmental changes and the advantages and decision-making capabilities required to respond to complex and dynamic conditions, restructuring production systems is essential for this type of business. In this study, two types of improvement policies were examined: the impact of production policies on product demand and pricing to enhance competitive production costs, and the impact of capacity planning policies.

This issue was approached using agent-based modeling. An analysis of model behavior indicates that implementing production policies increases product costs, which aligns with competitive activities among companies and helps establish favorable pricing perceptions among customers. In this context, due to stable demand for the product, only an increase in production capacity was considered, implementing the leading capacity planning strategy. This strategy adds production capacity to respond to sudden changes in demand. The effects of two parameters—the capacity review period (Pp) and the production capacity expansion rate (Kp)—were examined. Experimental results show that increasing these parameters leads to higher production capacity.

To achieve higher net profits, it is recommended that supply chain alignment with customers' fundamental needs be prioritized, resulting in more consistent value and pricing. This can be accomplished through effective supply chain management that aligns with essential customer requirements such as product delivery time, design, packaging, inventory planning, internal and external transportation management, and procurement programs. This approach enables companies to determine prices based on tangible value created throughout the supply chain.

While cost accounting information cannot be overlooked when pricing products, companies must consider a combination of elements such as demand, competition, and costs to make appropriate pricing decisions. Failure to account for these factors results in incomplete and inefficient decision-making. Effective pricing requires gathering and processing relevant accounting, market, and competitor data. Additionally, staying informed about price changes and being aware of company goals and government policies are essential.

Another important consideration in pricing is negotiation-based pricing. Many industrial products are sold at prices determined through negotiations between buyers and sellers. This pricing approach stems from the nature of industrial products, which are not directly or finally consumed by industrial buyers. Negotiation-based pricing is common and significant in large-scale contracts for industrial products.

To implement an effective pricing strategy, companies must consider their pricing position, strengths and weaknesses, threats and opportunities, pricing goals and strategies, and pricing review and control mechanisms. Thus, managers should treat pricing and price determination as a strategic process rather than an automatic or quick decision. Today, the need to establish appropriate pricing is viewed as a strategic program for managers.

Pricing in industrial marketing is a highly complex and debated topic. To succeed in the market, companies and managers must develop a comprehensive understanding of competitors' activities and competitive strategies. Before engaging in pricing for industrial marketing, it is crucial to understand the characteristics of the industrial market compared to the consumer market. Industrial and consumer markets differ in terms of competition, market characteristics, product attributes, buyer behavior, distribution channels, and pricing features.

Researchers are encouraged to explore other modeling methods and compare results, such as dynamic system modeling, structural and interpretive modeling, simulation algorithms, dynamic non-cooperative game theory, and others.

Authors' Contributions

Authors equally contributed to this article.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

All procedures performed in this study were under the ethical standards.

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