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Analyzing the Manual and Automated Assembly Line Using System Dynamics (SD) Approach

Nima Pasha[a], Masood Rabieh*[b], Gholamreza Eslamifar[c], Seyed Hossein Razavi Hajiagha[d]

[a] *Department of Industrial Management, University of Tehran, Kish International Campus, Tehran, Iran.*
[b] *Department of Industrial Management and Information Technology, Faculty of Management and Accounting, Shahid Beheshti University, Tehran, Iran.*
[c] *Department of Public Policy, Faculty of Management, University of Tehran, Tehran, Iran.*
[d] *Department of Management, Faculty of Management and Financial, Khatam University, Tehran, Iran., Tehran, Iran.*

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ABSTRACT

Improving the responsiveness to customers' orders is the goal of this research. Balancing the manual and automated production lines using proper equipment is crucial for the case study to reduce production costs and increase the quantity. The main problem in this research is responding to orders and demand using the proper equipment and machines in the production line. Using automated equipment can improve productivity and responses, but using advanced technology is not necessarily effective and should be organized in proportion to demands. As in this case study, there are complex cause-and-effects relations; using System Dynamics is very effective. Different productivity factors, delays, orders, etc., are considered to determine the proper production method and equipment in the long term. After that, behavioral reproduction and extreme condition testing validate the model and compare the automated production line equipment percentage usage. According to the volume of orders, the optimum case is suggested. Then, different scenarios related to customer volume are analysed, and finally, the policies are examined. As the simulation results in current conditions and market forecasting indicate, 67.2% of production line equipment should be automated. Any customer order changes can increase or decrease the results, which should be calculated accurately. Considering all the influential factors, the presented model helps the production managers have the best policy for choosing the production method. Using this method, considering some changes in the variables can be used in different industries as optimizing the production line equipment is the main key finding of this research.

Keywords

Manufacturing technology, Master production, Assembly line, System dynamics, Stock and flow diagram.

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****Corresponding author***
Email: m_rabieh@sbu.ac.ir

1. Introduction

Choosing the proper production method in the manufacturing systems is so high. In this subject, the effective factors are Breakeven Point (BEP), production capacity, and using technology. BEP is one of the evaluation and assessment techniques with an economical approach. In this technique, the relation between cost, income, and volume of production is determined. The costs of production are divided into two categories. One of them is fixed costs (FC), and the other is variable costs (VC) that have a direct relation with production volume fluctuation (Mottaghi and Hosseinzadeh, 2008). The BEP is calculated based on the Benefit-Cost chart, and it's gained from the confluence of benefit and demand probability distribution (Kazemi and Kasaei, 2011). The number of required equipment and human resources calculations is significant, too, and the nominal and actual capacity is required to calculate in proportion to demands (Chase and Jacobs, 2000).

Selection of the technology and production method in different conditions can greatly reduce production costs and capacity growth to respond quickly to customers. When the production volume is high, and the production line works continuously and full-time, the effects of using automated equipment are significant. The flexibility of manufacturing systems in competitive markets has different specifications, such as time of delivery and demand fluctuations (Rezae et al., 2021).

In this research, balancing between manual and automated assembly lines or switching between them is critical to optimize production line processes and accelerate customer order delivery. This research is done in the elevator control panel industry. Responding to the volume of orders in different conditions by choosing the appropriate manufacturing technology and production method is the main problem. Therefore, after the implementation of the model, the type of technology is examined in the form of an analysis of different scenarios to determine the amount of work to be allocated to each line (manual or automated) according to different market conditions.

If the volume of orders is low in the long run, a fully automated line is not justified (because a lot of costs must be incurred to set up a new line), and if it's a manual line and the volume of orders is high in the long terms, the number of lost orders will be increased. Changing the production line to an automated production line according to the calculated numbers is justified. Suppose the capacity difference in the current situation with the orders isn't very high. In that case, switching to another type of production line won't be efficient, and making some changes, such as overtime and shifts, is a better idea. When we face demand fluctuations significantly, it must be concluded that with the existing equipment, many orders are lost. Therefore fundamental changes in equipment technology are needed to increase capacity.

As the problem is complex and has causal relations, the stock-flow variables for materials and products are defined, and the model has different delays. We have these delays during the periods, and the problem variables affect each other. Thus, achieving the answer to the problem is a very complex task, so the System Dynamics (SD) model has been used in this research.

During the research, in section two, theoretical foundations and research background is done, and that part refers to the concepts of automation, production planning policies, and product control. In section three, related SD research and their used factors are investigated. The research methodology section explains the concepts of SD, simulation steps, and their definitions. Then the steps of this method are used in a case study in the electronics industry. After creating and validating the SD model, different scenarios are examined, and the results are investigated.

2. Theoretical foundations

Production planning is essential in manufacturing systems to utilize the material and human resources allocated to each task. It involves scheduling and organizing the manufacturing processes in a plant. These production processes require long-term, medium-term, and short-term scheduling. Master Production Scheduling (MPS) is medium-term planning related to the company's strategies and operational planning. It includes capacity constraints, forecasting, production planning, lead time, customer orders, etc. (Nabovati and Taherian, 2012). Final assembly scheduling (FAS) or Shop-Floor Control is short-term and generally known as production activity control. The relevant department or production control unit has the task of scheduling and monitoring daily production in the workshop production, as well as sequencing operations and monitoring production processes (Feizabadi et al., 2008). As automated equipment reduces physical work, system interaction is also affected. In this status, workers' goal is growth in automation, and they manage different machines (Frank et al.,2017). Different methods have been proposed to analyze the performance of manufacturing systems, such as assembly lines, lead Time, WIP, demand response, etc., which are the critical factors considered (Park and Jingshan, 2018). Using advanced technology will improve utilization decrease setup time and WIPs, and LTs, so evaluation of this advanced manufacturing systems performance that uses these technologies should be analyzed to get the optimal value of utilization and production throughput (Kashif et al., 2017).

3. Literature review

3.1. The investigated application in the SD area

In Table 1, some samples of research related to SD areas in a manufacturing system, manufacturing technology, demand forecasting, and supply chain are done, and at the end of this table, the main variables and required acts are explained. These seven factors were chosen as they have a lot of effects on this study and considered all of the required aspects for this production line.

All seven factors are used in this study, and the investigation related to production planning variables at all levels, such as SS, Backlog, external factors, capacity, BEP, etc., is done in manual and automated production lines.

3.2. Research gap

SD modeling can be a powerful and useful tool for analyzing a study with complex and nonlinear relations. So, SD can be the proper approach by considering the various variables such as production and material planning and related delays and demands for switching between manual and automated production lines. The production, inventory, and forecasting-related variables have not been used as in the previous research. This paper aims to find the best combination of the manual and automated production lines to reach various policies and scenarios testing with simulation methods to respond to the orders. In addition, it's possible to add other variables in the future.

Table 1. Researches investigation related to SD application in supply chain and manufacturing systems

Researches	Factors							Research variables
	Environmental and Governmental Factors	Demand Forecasting	Demand Forecasting and Capacity	Manufacturing Systems	Supply Chain	Production Planning	Manufacturing Technology	
(Yongan et al., 2012)		✓	✓		✓	✓		Proposing a breakpoint in the leagile supply chain to improve the information system between components, agile the production, and standardize it
(Deif, 2015)				✓			✓	Investigating the variables of production demand rate, production cost, demand diversity goals, scalability cost of technology use, capacity scalability delays, production rate, etc.
(Hoseini et al., 2016)		✓	✓		✓			Checking the variables of warehouse and retail demand, customer demand, factory warehouse, production rate, order rate, distribution changes, reliability storage, consumption rate, etc.
(Rabieh and Yasubi, 2017)		✓	✓		✓			Checking demand fluctuations and variables of WIPs and raw material inventory, inventory of products, orders, delivery time, delivery rate, etc.
(Tama et al., 2017)		✓			✓			Using inventory and demand variables in the model to optimize the profits
(Gallego, and García, 2018)		✓		✓			✓	Investigation of forecast variables, demand, capacity, production time, maintenance, and repairs
(Fontesb and Freires, 2018)		✓	✓		✓			Investigating the variables of resources, demand, production, capacity, overcapacity, and orders in areas related to sustainable and renewable energy supply chain
(Olivares-Aguila, 2019)		✓			✓	✓		Examining unpredictable information variables, active and responsive strategies, distribution planning, and orders
(Jahanian et al., 2020)		✓			✓			Investigating the variables of demand response rate, delivery cost, etc., in the subsystems of demand, sales, and investment

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4. Methodology

The system approach means having an integrated view of systemic thinking, including system goals, system elements, system environment, feedback, casual-loop relations, behavior pattern and system delay (Ghobadi, 2011). SD is used in this paper because it's a valuable tool to identify the causes of dynamic behavior in different systems based on system thinking (Bastan and Zarei, 2021). In general, the steps of the modeling process include the 5 main steps of problem definition, mathematical relations, dynamic hypotheses, formulating, testing, and finally, policy design and evaluation (Sterman, 2000). The primary purpose of the research is to select the appropriate share for the production unit for the case study from each technology. In other words, it's related to identifying the proper combination of manual and automatic production methods. So, the main variables in this model have produced products and their cost in manual and automatic modes. Figure 1 shows the research steps.

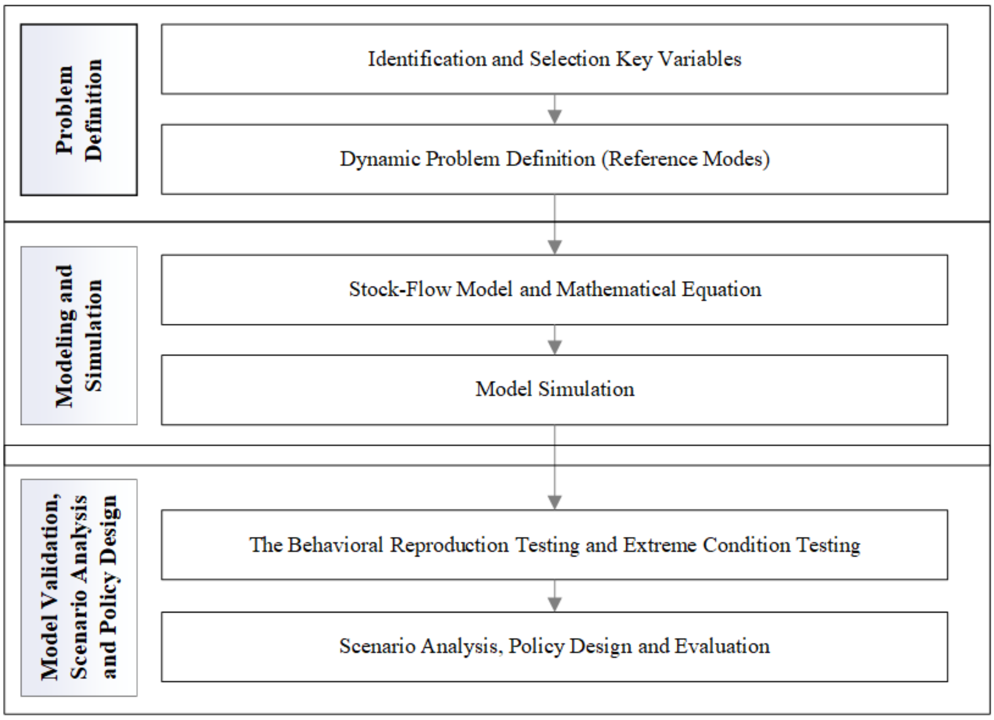

Figure 1. Study steps

The volume of production and the number of customers' demands should be matched. For lean manufacturing, the primary inventory period needs to be minimized (Mehraban, 2005). In the Stock-Flow diagram, the visible inventory is calculated from the deviation of the output rate and the raw material entering rate. The production planning is set based on the demands. Other variables such as Safety Stock (SS), Lead Times, and BEP are effective on them. Based on the production flow variables of two production lines, there are some product delivery influences on the demand variable, as the mathematical formulas show. Also, production planning is calculated based on that.

4.1. Problem definition

In this study, balancing the manual and automated production lines and specifying the share of each method for growing the production capacity in proportion to the demands is the main problem of the factory. This balance leads to more customer satisfaction and market development.

The output of two manual and automated production lines is very important to set in proportion to demands. So, which method can better respond to customers and increase the production capacity at a lower cost should be investigated.

Figure 2 shows the data about orders and lost ones in the last seven periods to show the market status.

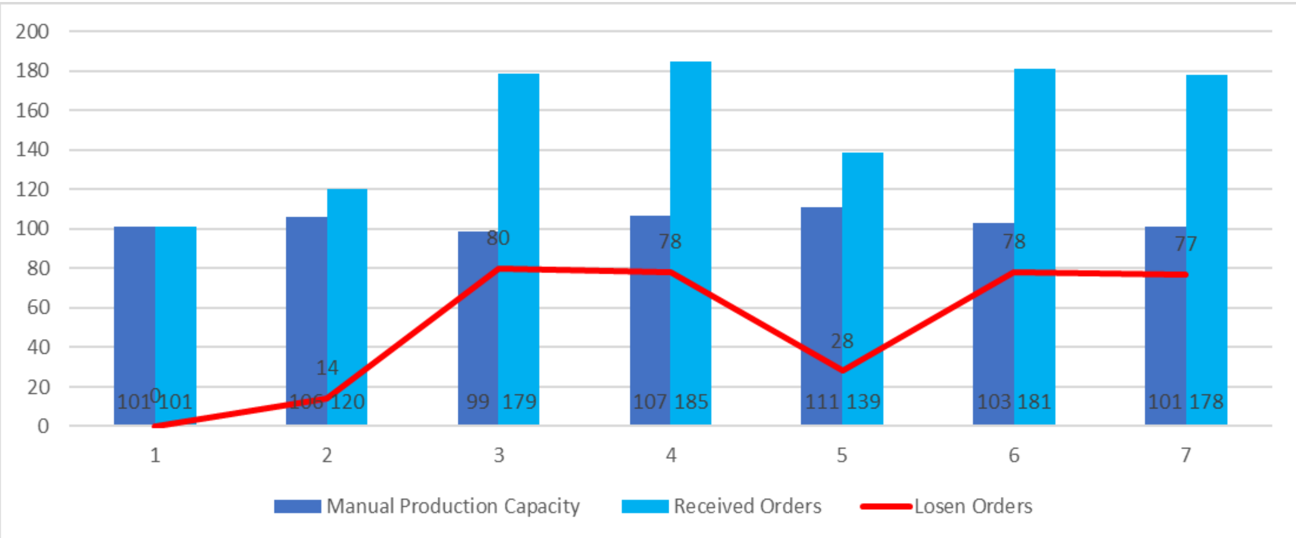

Figure 2. Orders and loosen customers

Figure 3 shows the case study production capacity comparison in the two statuses of production lines. This production line simultaneously has had both manual and automated systems in the past because of the nature of its products. One part of the product has less complexity in manufacturing processes and needs fewer tests.

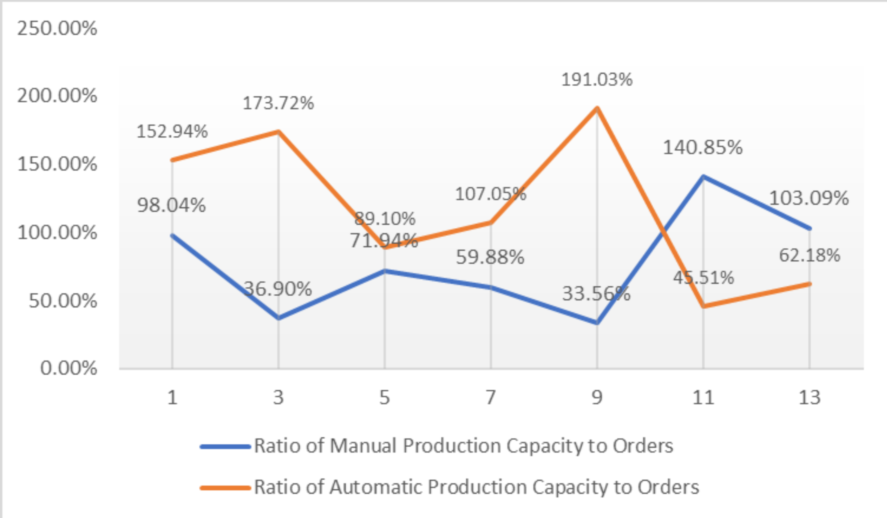

Figure 3. Orders and production capacity comparison

As there is high fluctuation in orders and production capacity is limited to switch from two production line methods, it's imperatively to investigate this accurately that is it possible to hold the production line in the manual status and have other policies such as overtime mechanism or add shifts to response the demands or not. In this case, changing the production line does not cost much; both can be used simultaneously.

As Figure 3 shows, the high volume of customers' orders is lost in the manual production system, and the low production capacity is the reason. Currently, the production line in the manual status provides a limited number of products, and its capacity is less than the automated status, leading to losing many customers. Besides, Figure 4 determines the production capacity ratio for both product lines to the manual one; obviously, responding to all demands and orders is impossible. There is an important notice that shifting the production method should be done in proportion to the demands. If the volume of products is not very high, using the automated equipment will cost a lot and have higher depreciation. So, choosing the manual and automated production lines or both of them to increase production capacity to better respond to customer's orders is the primary goal of this research. The balancing between the production capacity in both assembly lines should be considered. Relation between modelling and literature are:

4.1.1. The model's internal variables

Safety Stock, Master Production Scheduling (MPS), Material Requirement Planning (MRP), Shop-Floor Control (SFC) and required delays are the internal variables considered in the model.

Safety Stock is the volume of inventory in the warehouse stored to prevent the probable shortage of material during their consumption in the production line. The equation of Safety Stock is $SS = Z.\sigma$ (Korponai et al., 2017).

Another considered variable in this model is manufacturing technology. Using the equipment, machines, and vehicles for the automation of manufacturing processes is very important to increase the productivity of the production line, and it's called automation (Mottaghi and Hoseinzadeh, 2008). Technology development is divided into three periods of the industrial revolution, the primary status, the emergence of semi-automated systems, and the replacement of advanced technologies can be divided (Kazemi and Kasaei, 2011). Using automation in the production management systems, using automated equipment in the manufacturing systems, information systems, etc., and designing the drafts of products is Computer-Aided Design and Manufacturing (CAD/CAM) (Mottaghi and Hoseinzadeh, 2008). The software EPLAN is a CAD software to design the control panel and the automated equipment of Rittal company used to manufacture the products based on the drafts designed using ePlan (www.rittal.us).

4.1.2. The model's external variables

Governmental and environmental factors, customers' demands, and other costs are the model external variables considered in the model.

* Using the Input Analyzer of Arena Rockwell Software estimates the statistical distribution (Keceli and Aydogdu, 2013). After entering the input data and observing the histogram chart and its results, the nearest statistical distribution is chosen (www.arenasimulation.com). For instance, this software shows the fitted statistical distribution in the Normal distribution with μ average and σ standard deviation and Z value (Ross, 2010).

5. Simulation, data analysis, and results

Modeling includes five primary stages problem definition, mathematical relations, dynamic hypotheses, formulating, testing, and finally, policy design and evaluation. These steps include (Sterman, 2000).

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5.1. Model description

This model investigates each of the internal and external factors for the assembly line of electrical panels and revision boxes. One production line is manual, and another is automated (as various robots work in this line) and use Rittal Company devices.

This model considers different factors such as human resources factors, production method, equipment, raw materials, and money (which are different in the two types of assembly lines). In addition, BEP in the single product type and production planning is also considered in the model. Thus, in this production line, BEP, according to the calculations, is different for manual and automatic modes, which have also been modeled. This dynamic model will be simulated for 100 times by VENSIM software. Then the behavior of stock and flow variables and other auxiliary and exogenous variables will be examined.

Reviewing the observed problems and delays, the required corrections are proposed and their impact on the system is investigated. Parameters affecting the observed problems in the two classifications of internal and external factors described are examined and based on them and the identified relationships, effective solutions are provided. In this model, two assembly lines to produce electrical panels and revision boxes are examined and the factors of each are identified. Some variables in this model are used in both product lines. For example, raw materials in supply chain planning, government factors and legislation, and the factors influencing them have been used as a common variables. Still, most of these variables have been examined separately for each process and production line.

In revision box assembly line production, ePlan CAD software, and wire-cutting machines, CAM software is used to spend less time and manpower. However, these devices' procurement cost is much higher as we surveyed Rittal company (www.rittal.us).

5.1.1. Production line 5Ms

The reason for considering 5M factors in this model is that these factors influence internal production processes and their capacity. Based on the internal factors affecting the production of products in this case study, their sub-factors are prepared in the following table. These factors have different relations for the two manual and automatic production lines, and their formulas and mathematical relationships are specified in the appendix. For example, the equipment used in the automated production line and the production method in this line has a completely different process from the manual line. In the manual production line, manpower is used for wiring the control panels. Still, in the automated production line, according to the planning and control panel wiring drafts, manpower is different (although some of them have been modelled according to the needs of the case study company, and in their opinion, other factors do not affect the results of the current model that can be added to the model in the future. For example, the variety of products, returns, and rework products, deficits consideration, new products development, etc.):

- The list of BOM and delivery time are reviewed for both assembly lines. Each factor affects the production system separately, which is examined separately in the modeling section.

5.1.2. The subsystem and model boundary diagram

In this section, factors outside the organization, such as laws enacted by the government, are examined. Figure 4 shows two production line subsystem diagrams for this case study.

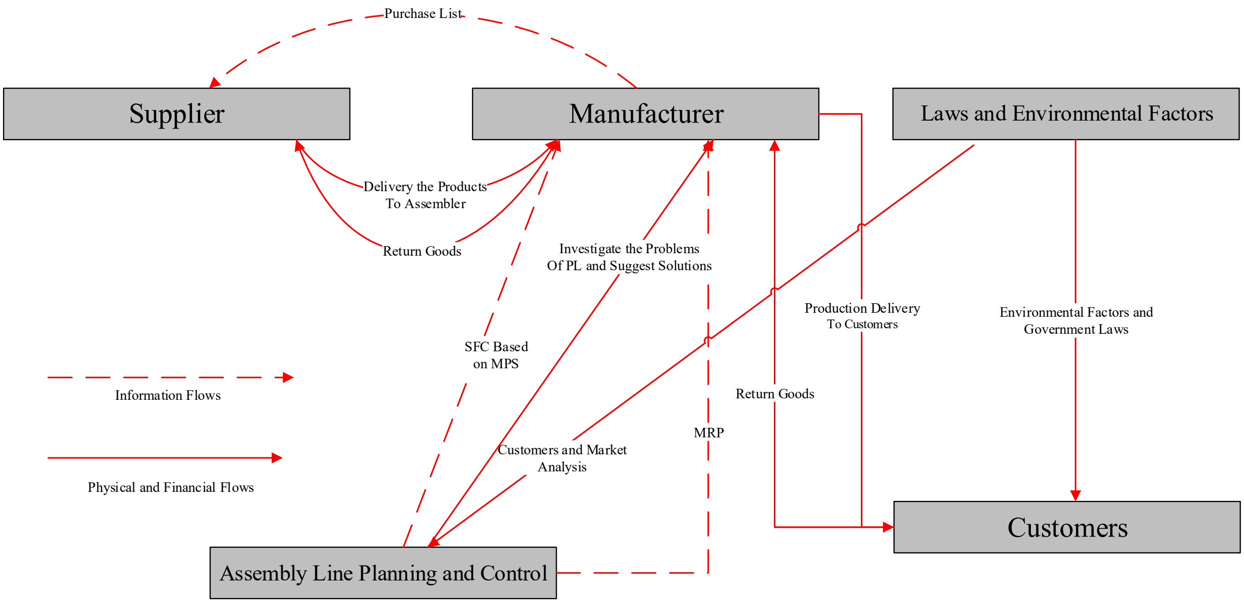

Figure 4. Subsystem diagram for this case study

Table 2 shows the model boundary diagram.

Table 2. The model boundary diagram for the case study

Endogenous variables	**Exogenous variables**	**Ineffective factors in the current model**
Production Capacity of Manual and Automated Production Lines, Production Cycle Time of Products, SS and Material Deficit Productions, Master Production Scheduling and Shop Floor Control (SFC), WIPs in production Line and Raw Materials, Production sales of products	Customer Orders and Needs, Fixed Costs, Variable Costs	Production Delivery and Distribution, Raw Material Ordering Method, Design and Development of Products, Operator Learning Rate

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5.2. Stock and flow diagram of the case study

Figure 5 shows the primary model of the factors affecting the production line that has been prepared and implemented. As shown in the model, 5M factors are considered in the production line. Factors related to orders and central production planning, such as MPS and SFC, are also considered in the model. WIP or product inventory in the production line and production capacity are also considered in both manual and automated assembly lines. Entry of material depends on production amounts starting from workstations with greater volume from obtained BEP (because this number must be more than the BEP, so it should benefit the company). The amount of MPS and then SFC to respond to the market needs too. It should be noted that currently, some products are done manually and some are done automatically.

Formulating model: Regarding the internal mathematical relations between two manual and automated production lines and the system boundary mentioned, the final model is drawn in Figure 5. The upper production line in the figure is manual and the lower production line is automated. The mathematical relationships of the model and their units are also explained at the end.

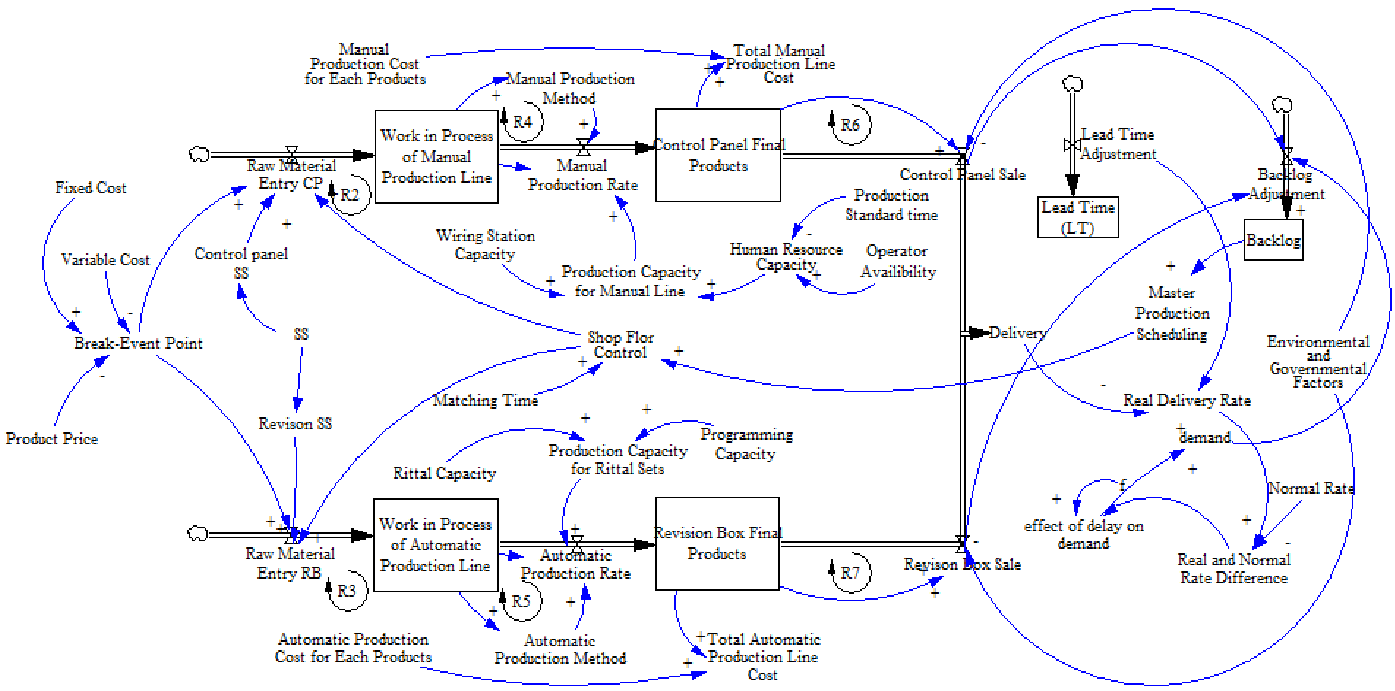

Figure 5. Model of the system (stock and flow diagram)

Also, by comparing the 5M factors in the two manual and automatic assembly lines and their details, all the influential factors that have a significant impact on production performance are considered in this dynamic model. These factors are gained from the interview and meetings with managers and experts in the production system, and their relationships are considered in the model. Therefore, classifying these factors has given a complete view of the production system to define the variables.

The defined loops in the model: Loop related to raw materials entering the production line and flow and stock variable mode of WIP products in the production line, loop of WIP and production rate of products, flow and stock variable loop with product delivery in two manual and Automated production lines as defined.

Defined delays in the model: The variable of raw material entry in the manual and automated production line as calculated from MPS, SFC, and the effect of demand which is Delay1 type. These delays are defined as the plans are organized, for example, until receiving the next steps, getting orders and announcing to the production line, or preparing the material. So, these delays are considered. Their detailed formulas of them are explained in the appendixes. Figure 6 shows production line and order delays considered in the model.

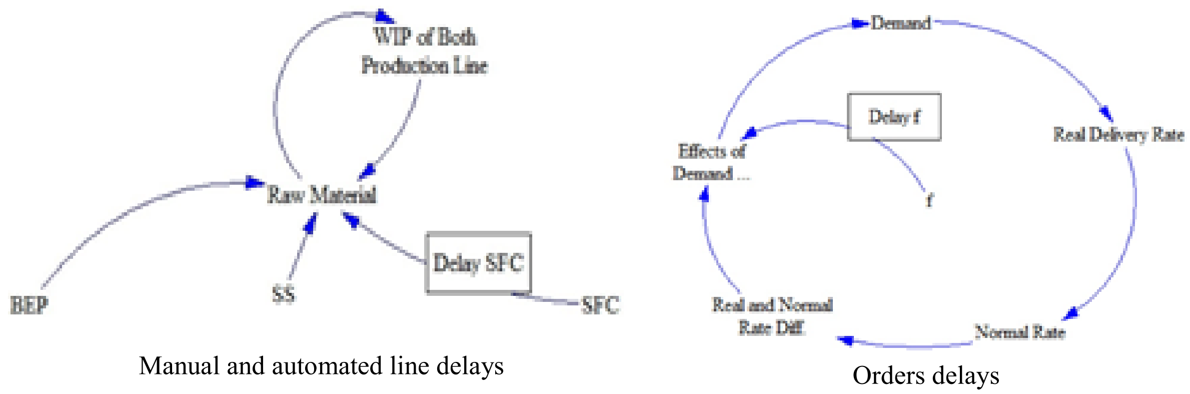

Figure 6. Casual diagram for the considered delays

5.3. Model simulation

In this section, the simulation results are investigated separately for all variables. In this model, the Input Analyzer section of Arena software has been used to calculate the statistical distribution of variables based on the previous data gathered. VENSIM software is used to model the problem. This software has been used to calculate the results, prepare reports in different views, and compare graphs for both production lines according to our needs. Figure 7 shows the model, which is the VENSIM software output:

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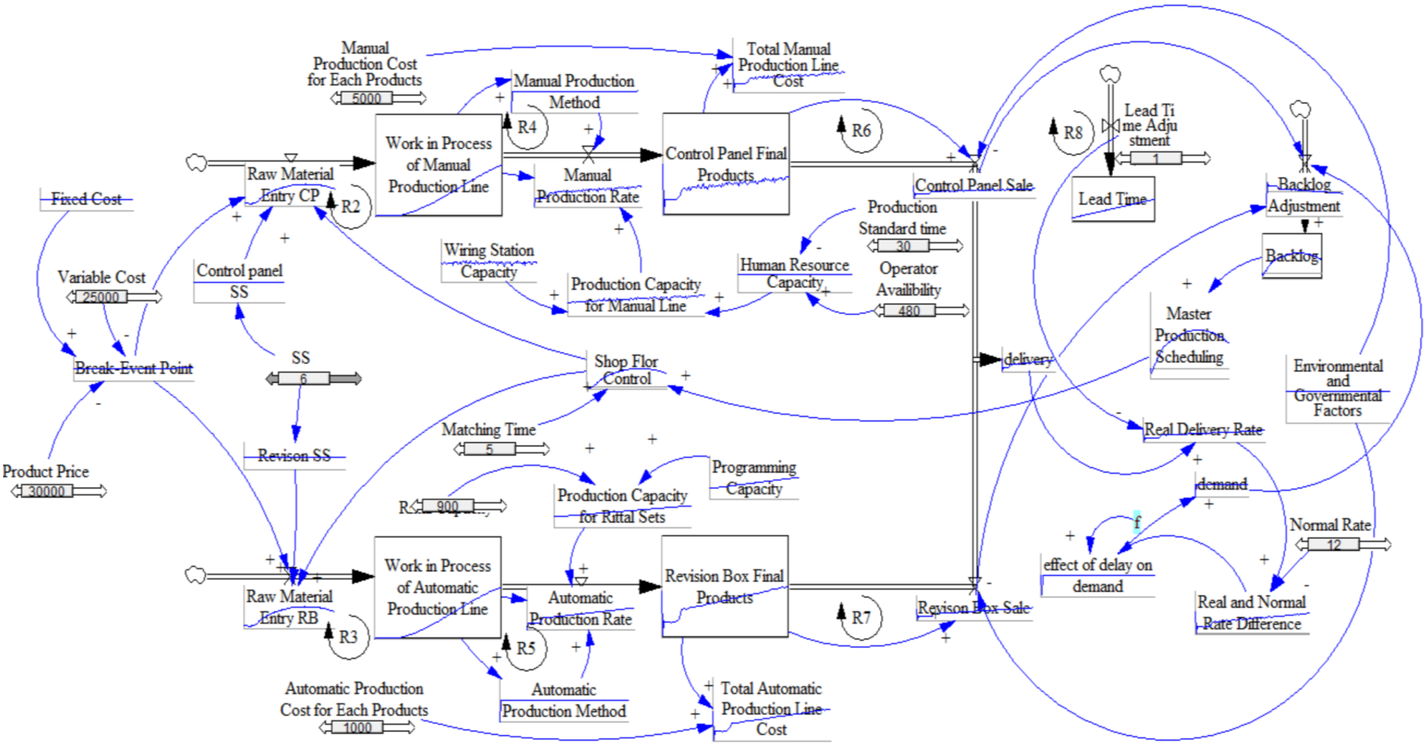
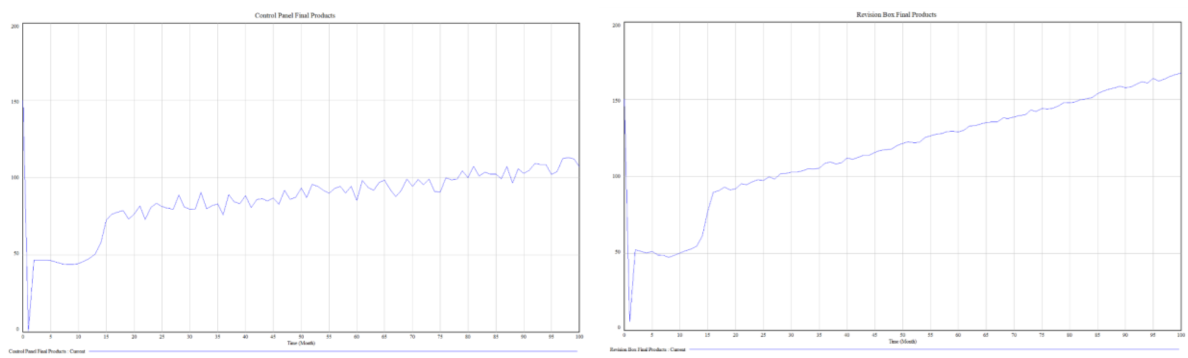


Figure 7. Model simulation by VENSIM software

Figure 8 shows the initial times and costs of implementing automated production machines. But after the period (App. 20 times), the production process will be routine, and the capacity will increase. In manual mode, the production capacity growth is so slow. Thus, this also shows the changing of the production line from manual to automated. Of course, changing some parts of the manual line to an automated one can be another option for production managers.

Also, according to the Figure 8 and based on past evidence from the sales unit, the average level of orders in this production line is close to the amount of revision box production. In general, as the behavior of variables shows, the manual line cannot respond to the orders in the current situation according to the volume of orders considered in the model. Also another goal of this model is to minimize the value of the Backlog.



(a) Control Panel Final Products (b) Revision Box Final Products

Figure 8. Comparison of the number of finished products in two types of manual and automated production systems

Figure 8 compares the number of final products in two types of manual and automated production systems.

5.4. Model validation

Behavioral reproduction testing is one of the tests to check the model validation. So in this test, it will be determined whether the model can reproduce the behavior shown by the real system (Menassa and Peña, 2009). This way, the behavior is reproduced to ensure the simulation results are near-real. To perform this test, the real prepared data must be checked with the model simulation results (Sterman, 2000). This model uses behavioural reproduction testing, and the real data related to production capacity are examined with the model's simulation results. A comparison of model simulation results for manual production mode variables and real mode variables is specified in Figure 9.

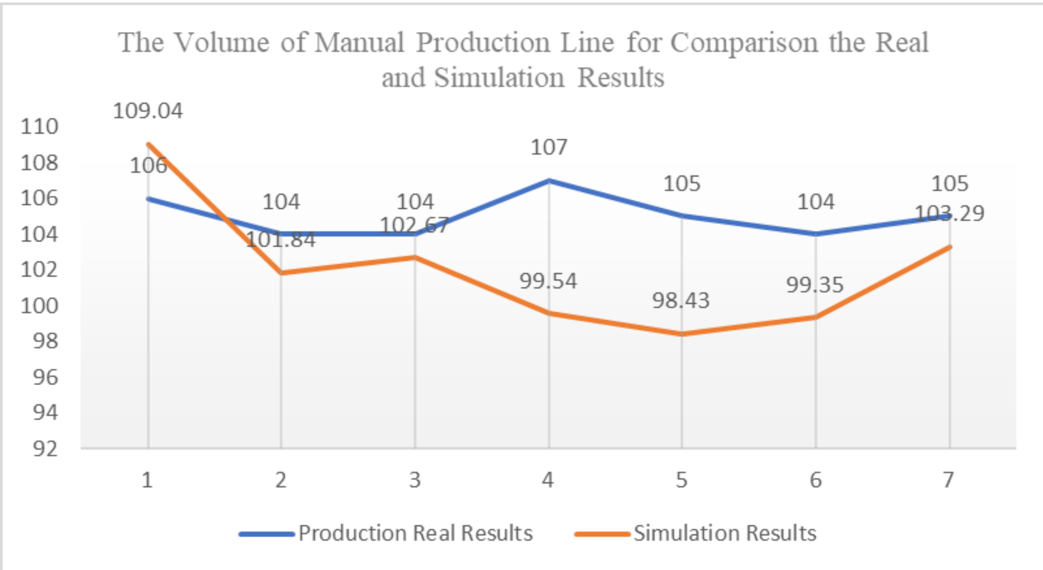


Figure 9. Comparison of the model of simulation results for stock variables in manual production mode and obtained real results

Table 3 shows the calculation of the mean square error relative to the comparison of real and simulation results of the model:

Table 3. Table of mean squares of error (MSE)

f_i	y_i	
109.04	106	$\text{MSE} = \frac{1}{N}\sum_{i=1}^{N}(f_i - y_i)^2$
101.84	104	
107.6	104	$f_i =$ Value returned by the model
99.54	107	$y_i =$ Actual value
98.43	105	N = The number of data points
99.35	104	MSE = 19.86
103.29	105	

The relation between this diagram and Figures 4 and 5 also shows frankly that the manual production line cannot respond to production orders in the current situation. Also, due to the above chart and unlimited customer orders, the manual mode imposes many lost customer costs on the system. Of course, by automating the production line, production capacity will also be increased (to 160 products), which should be proportional to the volume of orders. In other words, in this case, 67.2% of the automated mode is better. The behavioral reproduction testing and comparing the orders with the capacity of the manual mode indicates that traditional and manual production is not a good option for the current situation, according to the orders.

Another critical issue that should be considered is whether reducing the volume of orders in the automated system is still suitable. Certainly, In this model, it is possible to examine this issue in detail. By changing the volume of forecasted orders, it is possible to understand how many orders and the manual production system is sufficient. In this model, we considered the BEP and production scheduling (obtained from the volume of orders), and the production line capacity differed in both manual and automated modes. Still, in this case, the volume of orders is so high. And also, manpower and the traditional manual method are very expensive and unfeasible.

By reducing the market needs for the software, Table 4 is obtained that it includes the comparison of automating the production line according to the market demand, which is obtained as follows:

Table 4. Investigate and compare the percentage of automated production line equipment according to the volume of orders

Current status according to the volume of orders							The degree of automation of the production line according to the orders			
Demand		Output	Remained Orders	Automated Production	Manual Production	% of Remained Orders	% of Automating the Production Line as Needed	% of Manulling the Production Line as Needed	Perfect Production in Automated PL	Perfect Production in Manual PL
Demand -40	180	131.15	48.85	157.4	104.9	27.14%	43.100%	56.90%	118.209	61.96
Demand -20	200	134.45	65.55	162	106.9	32.78%	55.600%	44.40%	151.242	48.738
Demand	220	137.85	82.15	166.8	108.9	37.34%	67.2000%	32.80%	184.65	35.36
Demand + 20	240	141.75	98.25	172.4	111.1	40.94%	79.8000%	20.20%	218.127	21.965
Demand + 40	260	145.7	114.3	178	113.4	43.96%	92.2200%	7.78%	251.43	8.63
Demand + 50	270	149.05	120.95	183.6	114.5	44.80%	97.4000%	2.60%	267.55	2.19

The numbers in the above table are obtained from the software output and are calculated after changing the amount of market demand. However, due to the cost of transferring some part of the automated production line to the manual type or vice versa, it is recommended to change the complete production line to the automated type in the current situation. As Table 4 illustrates, in the current situation and according to the results of the model, 83.45 number of products is the difference between the sum of variables (based on the order) minus the production line delivery, so after balancing between two production lines, it will be possible to increase the capacity in proportion to the orders and customers' need.

The model must be stable in extreme condition testing. This test can be done in two methods. Direct inspection of equations is the first method, and simulation is another (Sterman, 2000). Extreme conditional testing is related to some basic behavior tests. This test is related to the correct operation of stock variables. In this method, all the equivalents of the model are examined separately (Barles, 1996).

At the end of this paper, in the "appendix" part all of the used equations are described. Equations 3 and 8 are related to the single product case study; accordingly, the BEP is calculated. Still, the number of materials that should be entered into the production line is the maximum of BEP and the number of SFCs, so this logic is the same for both manual and automated production lines. It should be considered that the case study production system is Make to Stock (MTS).

Equations 4 and 5: The production process begins for manual and automated production lines based on the raw material entering the system.

Equations 6 and 7: WIPs, after the completion of production processes, become the final products, and the sold products must be reduced from them. Also, the production method, production capacity, and also labor of the two production lines are different, which are also considered in the model.

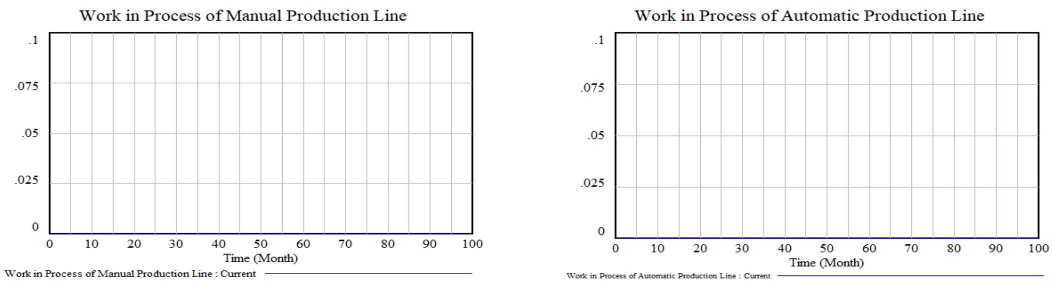
Equation 22: This equation relates to deficits that accumulate in the Backlog Adjustment.

Equation 23: This equation is related to the period from order to delivery of the raw material, which is Lead Time Adjustment accumulated with the initial value of 1.

The extreme condition testing for the case study model is considered as follows:

The following figure shows three graphs related to each case's extreme condition testing results. By minimizing the model inputs, the results are compared with the main results of the problem. The results of the leading and final model are marked in red color and the results of the model related to the input of the model minimization are marked in blue color.

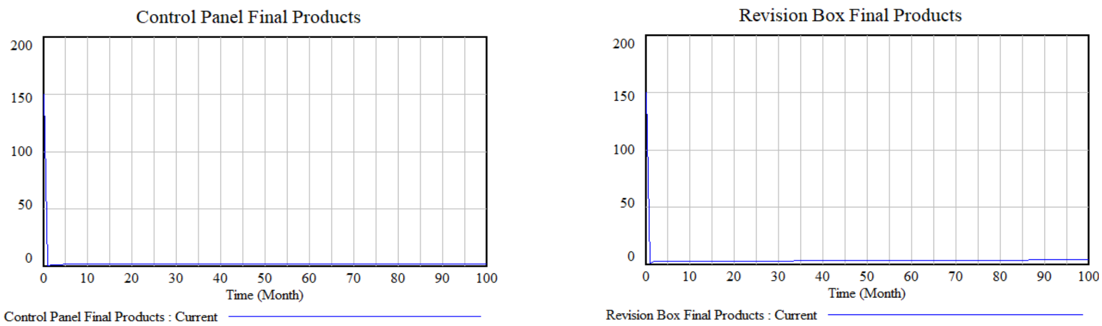
1. Reduce the interval of raw materials to zero (for both manual and automated production lines): A very small number of materials should enter the production line. The MPS and SFC are set, but no material enters the line, so we do not have production. In this case, the production and inventory of products are zero. Hence, the behavior of the stock variables in the inventory mode for products in both manual and automated lines was as follows (Figure 10).



(a) WIP of Manual Production Line (b) WIP of Automated Production Line

Figure 10. Comparison of the results of model in extreme condition testing with zero level of raw material

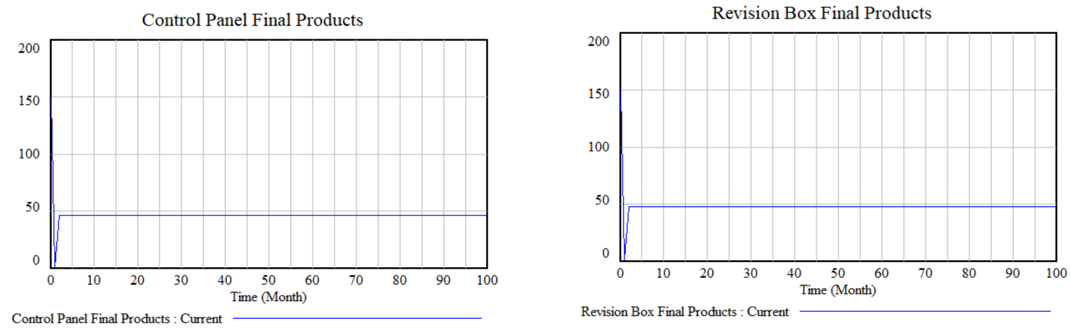
2. Reduce the capacity of the production line to minimum volume (for both manual and automated production lines): In this case, we have demand and purchase order, but the capacity of the manual production line means person/hour, and the capacity of the automated production line means the production capacity of automated machines is reached to minimized level. In this case, the model behavior for produced products in manual and automated lines was as follows (Figure 11).



(a) Control Panel Final Products (b) Revision Box Final Products

Figure 11. Comparison of the results of model in extreme condition testing with minimum demand

3. Reduce the amount of demand to zero: In this case, the amount of MPS and, conversely, the production plan at the workshop level or SFC is adjusted according to the amount of demand, and as a result, the material supply plan is changed accordingly. In this case, only the amount of SS is generated. The model behaviour for the final products produced in manual and automated lines is as follows (Figure 12).



(a) Control Panel Final Products (b) Revision Box Final Products

Figure 12. Comparison of the results of the model in extreme condition testing with zero demand

Also, a system improvement test is done and after increasing the capacity of the automated production line, the number of products in this line has grown.

5.5. Model scenario analysis and policy making to choose best decisions

Defining different scenarios aims to examine the system's behavior in market conditions. That is the basis for considering these scenarios to examine the changes in demand, the amount of MPS, and their impact on the system in this case study. Table 4 compares the percentage of automated production line equipment according to the volume of orders. Regarding the different modes of the system and production methods in these scenarios, the following policies are proposed for the production method.

5.5.1. Scenarios studied on exogenous variables

With increasing or decreasing the external factors and increasing the production volume, if the production line has many changes, it is recommended that the manual production line be located automatically. Because its production cost and capacity are higher in this case, the automated production line does not change and stays automated.

By increasing or decreasing external factors and decreasing the production volume, if the production line does not change much by 20, it is suggested that the automated production line be changed to type manually. Because its production cost and capacity are higher in this case, the manual line should not be changed because automating the line will cost a lot.

Balancing between the manual and automated line is another scenario considered for the production line. In the current production line, transferring part of the technology to the purchase of Rittal company's automated wiring devices and then training manpower for them can have a lot of side costs, and with a large volume of orders, this work will be recommended, and it is possible.

By increasing or decreasing external factors and decreasing the production volume, if the production line has many changes, it is recommended that the manual line be located automatically. Because its production cost and capacity are higher in this case. The automated line is also recommended not to be changed. Applying the changes to the production line makes it easier to change the programming of devices for automated equipment. Figure 13 shows the production method according to the volume of orders and possible changes comparison in four cases.

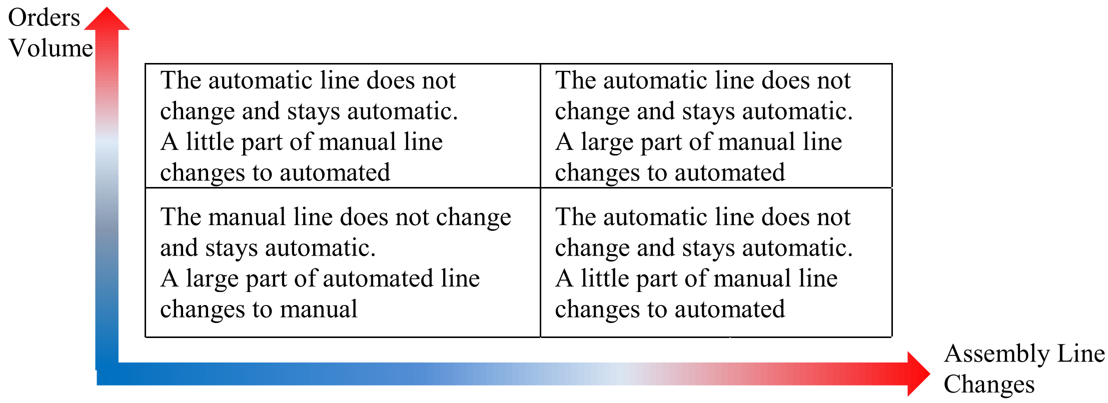


Figure 13. Determine the production method according to the volume of orders and possible changes in the single product line

According to table 4, we investigate the following scenarios with the changes in the normal rate that cause a change in the endogenous variable of demand:

Investigate the first scenario (pessimistic scenario means reducing demand and consequently reducing production): By reducing demand from 20 to 40, the best mode is to have a production line for mode (Demand - 40) with 43.3% automated production system, which in this case 118.2 of products should be produced automatically and 9.61 of products should be manufactured manually, the total number is 180, which fully covers the demand received from customers. The best mode is to have a production line for the mode (Demand - 20) with 44.6% automated mode; in this regard, 151.2 of products should be produced automatically, and 7.48 of them should be produced manually, the total of them is 200, which is fully covered the demand received from customers.

Investigate the second scenario (middle scenario): By keeping the demand constant, the best-case scenario is to have a line with 64.67% automatic mode. Which fully covers the demand received from customers.

Investigate the third scenario (optimistic scenario: it means increasing demand and consequently the profit of the production unit): With increasing demand from 20 to 80, the best case is to have a line for the mode (Demand + 20) with 79.9% automated production, which in this regard 218.1 of the product should be produced in automated line and 21.9 of products should be produced manually, so the total of 240, which fully covers the demand received from customers. The best mode is to have the production line for the mode (Demand + 40) with 92.1% automatic mode, which in this case 251.43 of products should be produced automatically and 8.6 products should be produced manually, the total of which 260 (Figure 14).

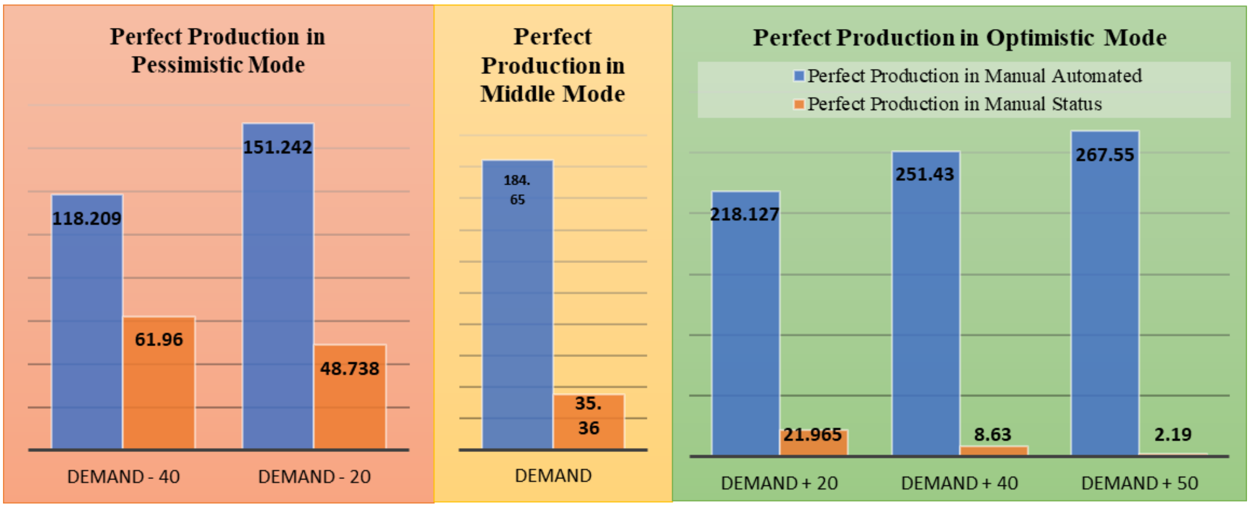


Figure 14. The status of perfect production quantity in three scenarios (pessimistic, moderate, and optimistic)

Investigate the fourth scenario (optimistic state of production capacity): By reducing the production capacity of human resources in the manual line by 0.8 times, the number of manufactured products in the defined conditions in the model for the manual line will be reduced by 90.

Investigate the fifth scenario (pessimistic state of production capacity): By increasing the production capacity of human resources in the manual production line by 1.2 times, the number of manufactured products in the defined conditions in the model for the manual line will decrease by 127.7.

Manual production has much less capacity than automatic mode and human resources capacity in manual mode is minimal. Still, in automated mode, it can be adjusted and programmed according to a specific schedule and work full time. The following diagram compares the workforce capacity of workstations and the production capacity in an automated manufacturing system programmed in the software. By reducing the number of human resources or production capacity, the production capacity of the manual production line will decrease.

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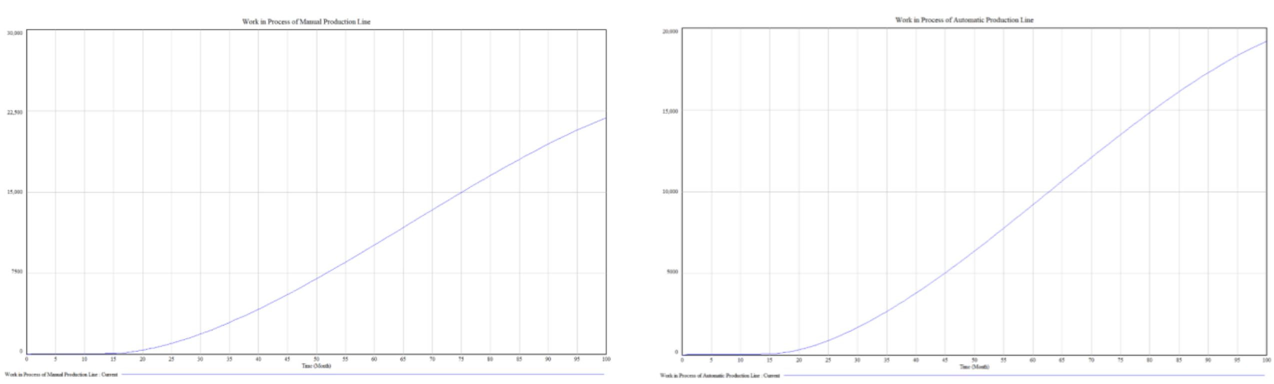
5.5.2. Policies examined on endogenous variables

The proposed policies in this case study that are related to changing the structure of the model and affecting the parameters are as follows:

Policy to change the volume of products in the MPS period and, therefore, its number of products variety each time the program is optimized and examined. Delay reduction policy considered from the MPS to the SFC level to accelerate the response to orders. Figure 15 shows the WIP inventory in two manual and automated production lines in the 100-time units. The charts in Figure 15 compare the WIP inventory in two manual and automatic production lines.



(a) WIP of Manual Production Line (b) WIP of Automated Production Line

Figure 16. WIP inventory analysis in two cases manual and automated production line

6. Conclusion

The research gap in this paper is using SD to consider the various variables to switch between manual and automated production lines properly. This research aims to find the best combination of the production line equipment to pass demands on time.

In this model, different factors related to production planning are considered. Also, this model can be used for choosing the advanced manufacturing equipment that distinguishes this research from previous ones. However, another variable can be added to this as that system needs. Migrating from basic technology to the next generation of the industry can be very important, so developing this model with more related variables can be possible for future studies.

In summary, the percentage of using automated equipment in the current status of demand is 67.2%, and, in this status, the perfect automated and manual production are 184.6 and 32.2, respectively. Different factors such as BEP, MPS, SFC, backlog, raw material lead time, delivery rate, demand, production capacity for each status of production, and production costs are used in the SD model to solve the problem. Then, the behavioral reproduction testing for this model is investigated to validate the model, and the production volume in the manual method is compared with simulation results. One of the main parts of this research is choosing the proper production line to balance the user manual and automated equipment in proportion to customers' demands.

Disclosure statement

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

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Appendixes: Mathematics formulas details in the model

In this model, BEP is considered for the production planning, and for production from the first production station, the maximum break event-point point and the number of production plans obtained from the master production scheduling are considered. Also, in this model, the BEP is considered for the single product mode (Esmaeili, 2012), the formula of which is obtained as follows:

BEP = Fixed Cost / (Price – Variable Cost) (2)

Other processes considered for modelling are the used material, the production line, the production capacity of operators and devices, as well as the production method. The master production scheduling is obtained from the difference between the market needs and the orders produced, and its output is planned at the workshop level, based on which the materials will enter the line. This program is obtained with some delay from the MPS.

The formula below shows the input rate of raw material in the automated manufacturing method:

Raw Material Entry CP = MAX ("Break-Event Point", Shop Flor Control) +Control panel Deficit+DELAY1(Shop Flor Control, 4)/2 (3)

The stock variable for Work-in-Process in manual manufacturing methods is:

$$\text{Work in the process of Manual Production Line} = \int_0^{100} (Raw\ Material\ Entry\ CP - Manual\ Production\ Rate), Stock(t_0 = 0) \quad (4)$$

The stock variable for Work-in-Process in automated manufacturing methods is:

$$\text{Work in the process of Automatic Production Line} = \int_0^{100} (Raw\ Material\ Entry\ RB - Automatic\ Production\ Rate), Stock(t_0 = 0) \quad (5)$$

The stock variable for products in manual manufacturing methods is:

$$Control\ Panel\ Final\ Products = \int_0^{100}(Manual\ Production\ Rate - Control\ Panel\ Sale), Stock(t_0 = 150) \quad (6)$$

The stock variable for products in automated manufacturing methods is:

$$Revision\ Box\ Final\ Products = \int_0^{100}(Automatic\ Production\ Rate - Revision\ Box\ Sale), Stock(t_0 = 150) \quad (7)$$

The formula below shows the input rate of raw material in the automated manufacturing method:

Raw Material Entry RB = MAX (Automatic Minimum Production + "Break-Event Point", Shop Flor Control) +Revision Deficit+DELAY1(Shop Flor Control, 4)/2 (8)

Master Production Scheduling and Shop Floor Control are calculated as the formulas below. Besides, between these two variables, there is a delay function:

Master Production Scheduling = (Environmental and Governmental Factors + Backlog)/10 (9)

SS = Safety Stock (10)

Error = Master Production Scheduling-Shop Flor Control (11)

The quantity of control panel and revision box are:

*Revision Box Sale = Revision Box Final Products-Environmental and Governmental Factors*3* (12)

Control Panel Sale= Control Panel Final Products-Environmental and Governmental Factors (13)

Other essential formulas of manual manufacturing are:

Human Resource Capacity = Operator Availability/Production Standard time (14)

Wiring Station capacity = RANDOM NORMAL (11, 17, 14, 0.75, 1) (15)

*Production Capacity for Manual Line = MIN (HR Capacity, Wiring Station Capacity) *5+RAMP(0.352,100)* (16)

The units of all human resources variables are Iranian Rials. Other important formulas of automated manufacturing are:

Programming Capacity = 4+RAMP(0.2, 16, 1000) (17)

Production Capacity for Rittal Sets=MIN(Programming Capacity, Rittal Capacity (18)

To calculate the production costs, the below formula is defined:

*Total Automatic Production Line Cost =Automatic Production Cost for Each Products*Revision Box Final Products* (19)

*Total Manual Production Line Cost = (Control Panel Final Products)*Manual Production Cost for Each Product* (20)

The units of all variable costs are Iranian Rials.

The orders variables of this model have the below formulas:

Real Delivery Rate = Delivery/Lead Time Adjustment (21)

Real and Normal Rate Difference = Real Delivery Rate-Normal Rate (22)

effect of delay on demand = f(Real and Normal Rate Difference) & f = [(-2,0)-(2,2)],(-2,0.2),(1.00917,0.307018),(0.275229,0.622807),(0,1),(0.238532,1.49123),(0.715596,1.77193),(1.27829,1.91228),(2,2) (23)

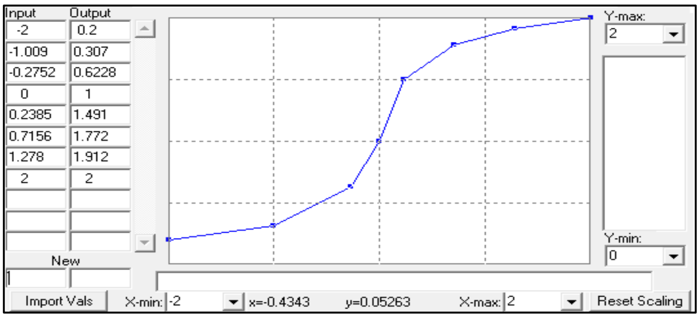

Figure 17. Effect of delay on demand

Backlog= INTEG (Backlog Adjustment,0) (24)

Lead Time= INTEG (Lead Time Adjustment,1) (Unit: Day) (25)

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Optimal Control Problem: A Case Study on Production Planning in the Reverse Logistics System

Mohammad Eshaghnezhad[a], Amin Mansoori [b]*, Sohrab Effati [b]

[a] *Department of Applied Mathematics, Faculty of Basic Sciences, Shahid Sattari University of Aeronautical Science and Technology, Tehran, Iran.*
[b] *Department of Applied Mathematics, Faculty of Mathematical Sciences, Ferdowsi University of Mashhad, Mashhad, Iran.*

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A B S T R A C T

Finished products and manufacturing plants are some elements of the production system in the supply chain, and there are other manufacturing plants. They produce work in process and finished products and hold them in warehouses. So, they need to plan and control production and inventories. Isolated planning and control by different manufacturers increase inventories in them, and then they must plan and control integratory. This paper presents an iterative approach for solving the optimal control problem with bounded control variables. The projection function constructs the iterative method to approximate the control law. Employing the approximation of control law, the approximation of state and the co-state variables are obtained. For this purpose, we apply the Hamiltonian of the optimal control problem. From the Hamiltonian, the approximation of control law and then the approximation of state law is obtained. A simple example is given to compare the results with another published paper. Also, a case study on production planning in a three-stock reverse logistics system with deteriorating items is derived to show the method's performance.

Keywords

Optimal control problem, Projection method, Production planning system, Reverse logistics system.

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****Corresponding author***
Email: a-mansoori@mail.um.ac.ir

1. Introduction

The study of the linear quadratic optimal control problem (OCP) with linear systems has a history of over fifty years. Many attempts have been made to obtain a satisfactory solution based on different approaches. The application of Pontryagin's maximum principle to OCP, as outlined by Naidu (2003) and Pontryagin et al. (1962), results in a system of coupled two-point boundary-value (TPBV) problems. Within the Dynamic Programming approach, the sufficient conditions for an optimal controller and the functional with prescribed derivative proposed in Kharatishvili (1961) lead to a set of partial differential equations called the Riccati Equation for the systems. Neural networks are also another approach that is desirable to use for researchers (Pooya et al., 2021; Effati et al., 2021). In these methods, the OCP changes to a system of equations and then by using some known neural networks such as Perceptron, the problem is solved.

In optimal control problems, it is sometimes the case that control is restricted to be between a lower and an upper bound, called a bounded optimal control problem. Bang-bang optimal control problems are also in which the optimal control switches from one extreme to another (i.e., strictly never in between the bounds). Bounded optimal control problems also have many applications, such as modelling infected diseases (Sweilam and AL-Mekhlafi, 2021; Liu et al.,2022; Ojo et al., 2022; Kovacevic et al., 2022; Sweilam et al., 2020), tank reactor systems (Göllmann et al., 2009), production planning systems (Hedjar et al., 2015; Pooya and Pakdaman, 2019; 2017 and 2018), etc. One major hurdle in the path of bounded optimal control problems discovery is the solution approach which is not similar to the methods without control restriction.

Motivated by the former discussion, we will present a novel method to solve delay and bounded optimal control problems. In this way, we applied the projection function to tackle the challenge of bounded control variables. We test the method on a case study to show our technique's performance. The case study is on production planning in a three-stock reverse logistics system with deteriorating items. The motivation of the paper can be summarized as :follows

1. Use the projection method to solve the OCP.
2. Solve a production planning problem modelled by an OCP.

The paper is organized as follows. The next section dedicates to the problem formulation and optimality conditions for OCP. The iterative method is proposed in Section 3. The case study is presented in Section 4, and the paper is concluded in section 5.

2. Problem formulation and optimality conditions

In this section, the problem formulation and the optimality conditions of the problem are stated in (1). Consider the OCP in the following form.

$$\min \mathrm{J} = \frac{1}{2}\mathrm{x}^{\mathrm{T}}(\mathrm{t_f})\mathrm{S}\mathrm{x}^{\mathrm{T}}(\mathrm{t_f}) + \frac{1}{2}\int_0^{\mathrm{t_f}}(\mathrm{x}^{\mathrm{T}}(\mathrm{t})\mathrm{Q}\mathrm{x}(\mathrm{t}) + \mathrm{u}^{\mathrm{T}}(\mathrm{t})\mathrm{R}\mathrm{u}(\mathrm{t}))\,\mathrm{dt}$$

$$\dot{\mathrm{x}} = \mathrm{Ax(t)} + \mathrm{Bu(t)} \qquad (1)$$

$$\mathrm{x}(0) = \mathrm{x_0}$$

$$\mathrm{u(t)} \in \mathrm{K}, \qquad \mathrm{t} \in [0, \mathrm{t_f}]$$

where $x(t)$ and $u(t)$ are piecewise continuous the state and the control vectors, respectively. Also, A and B are two matrices of appropriate dimensions and x_0 is the initial state. Moreover, $K \subseteq \mathbb{R}^m$ is a close set. The initial condition $x(t = 0) = x_0$ is given. The terminal time t_f is specified, and the final state $x(t_f)$ is not specified. Furthermore, $Q, S \in \mathbb{R}^{n\times n}$ is positive semi-definite and $R \in \mathbb{R}^{m\times m}$ is positive definite.

Now, we will state the optimality conditions of equation (1). Consider the following Hamiltonian equation for (1):

$$\mathrm{H}\,(\mathrm{x(t)}, \lambda(\mathrm{t}), \mathrm{u(t)}, \mathrm{t}) = \frac{1}{2}\mathrm{x}^{\mathrm{T}}(\mathrm{t})\mathrm{Qx(t)} + \frac{1}{2}\mathrm{u}^{\mathrm{T}}(\mathrm{t})\mathrm{Ru(t)} + \lambda^{\mathrm{T}}[\mathrm{Ax(t)} + \mathrm{Bu(t)}]. \qquad (2)$$

Where $\lambda(t)$ is the state variable. Based on equation (2), the optimality conditions can be stated as follows:

$$\dot{\mathrm{x}} = \frac{\partial \mathrm{H}}{\partial \lambda(\mathrm{t})} = \mathrm{Ax(t)} + \mathrm{BR}^{-1}(\mathrm{t})\mathrm{B}^{\mathrm{T}}(\mathrm{t})\lambda(\mathrm{t}) \qquad (3)$$

$$\dot{\lambda} = -\frac{\partial \mathrm{H}}{\partial \lambda(\mathrm{t})} = -\mathrm{Qx(t)} - \mathrm{A}^{\mathrm{T}}\lambda(\mathrm{t}), \qquad (4)$$

$$u(t) = \arg\min_{\{\mathrm{u}\in\mathrm{K}\}} \mathrm{H}\,(\mathrm{x(t)}, \lambda(\mathrm{t}), \mathrm{u(t)}, \mathrm{t}), \qquad 0 \le \mathrm{t} \le \mathrm{t_f} \qquad (5)$$

$$\lambda(\mathrm{t_f}) = \mathrm{Sx}(\mathrm{t_f}), \qquad \mathrm{x}(0) = \mathrm{x_0} \qquad (6)$$

Equations of (3)-(6) are known as a TPBV problem. The initial value of $x(t)$ is $\mathrm{x}(0) = \mathrm{x_0}$ and the initial value of $\lambda(t)$ is $\lambda(\mathrm{t_f}) = \mathrm{Sx}(\mathrm{t_f})$.

3. Projection method for solving OCP

Here, the projection method for solving the OCP is studied.

Consider the optimality conditions of OCP (1) stated in equations (3)-(6). Assume that the equation (7) instead of equation (5) in optimality conditions:

$$u(t) - P_K\left[u(t) - Z\big(u(t)\big)\right] = 0, \quad 0 \le t \le t_f \tag{7}$$

where $P_K(.)$ is a projection map and is defined as: (Eshaghnezhad et al., 2022; Mansoori and Effati, 2019).

$$P_K(u) = \arg\min_{v \in K} \| u - v \|$$

Also, $Z\big(u(t)\big) = -\frac{\partial H}{\partial u(t)}$. Note that, $P_K(.)$ is a piecewise function. Here, some results about the $Z(u(t))$ are investigated.

Lemma 1. $Z(u(.))$ satisfies the Lipschitz condition.

Proof. As $Z(u(t)) = -\frac{\partial H}{\partial u(t)} = R(t)u(t) + B^T(t)\lambda(t)$, so the proof is obvious.

Remark 2. According to the equations (3)-(6), when we want to obtain the solution to the problem, we should at first find $u(t)$ form equation (5) and then substitute in equations (4) and (3) the co-state vector $\lambda(t)$ and state vector $x(t)$ are obtained.

Now, in the previous discussion, we are going to settle down some iterative schemes to find the solution to the problem.

The projection method gives an iteration sequence of controls by the rule in equation (8):

$$u^{k+1}(t) = P_K\left[u^k(t) - Z\left(u^k(t)\right)\right], \qquad k = 0, 1, \dots . \tag{8}$$

We use the notation $Z(u^k(t)) = -H_u(x^k(t), u^k(t), \lambda^k(t), t)$ where $x^k(t)$ and $\lambda^k(t)$ are the solutions of the state and co-state equations, respectively, related to the control function $u^k(.)$ and u_0 is an initial control approximation. We consider the grid points $t_i = ih$, $i = 0, 1, \dots, N$ for $N = \frac{t_f}{h}$, the initial approximation $u_i^0 = u_0(t_i)$, $i = 0, 1, \dots, N-1$, and the definition of the $(k+1)$ approximation is given in equation (9):

$$u^{k+1}(t) = P_K\left[u^k(t) - \bar{Z}\left(u^k(t)\right)\right], \qquad k = 0, 1, \dots, \tag{9}$$

where $\bar{Z}(u_i^k) = -H_u\big(x_i^k, u_i^k, \lambda_i^k, t_i\big)$ and x_i^k, λ_i^k are obtained after applying the Euler method to the state and co-state equations using the control approximations u_i^k on the intervals $[t_i, t_{i+1}]$, $i = 0, 1, \dots, N-1$, i. e.,

$$x_{i+1}^k = x_i^k + h\left(Ax_i^k(t_i) + Bu_i^k(t_i)\right), \qquad x_0^k = x_0, \tag{10}$$

$$\lambda_i^k = \lambda_{i+1}^k + hH_x(x_{i+1}^k, u_{i+1}^k, \lambda_{i+1}^k, t_{i+1}), \qquad \lambda_N^k = S^k x_N^k. \tag{11}$$

Note that, from the above equations, the state and co-state vectors are computed forward and backward, respectively.

Remark 3 Based on Remark 2, u^k is obtained from equation (9) and then x^k and λ^k are provided in equations (10) and (11). Finally, by applying the obtained u^k and x^k the quadratic performance index can be calculated according to the equation (1):

$$J^k = \frac{1}{2}(x^k)^T(t_f)Sx^k(t_f) + \frac{1}{2}\int_0^{t_f}\left((x^k)^T(t)Q(t)x^k(t) + (u^k)^T(t)R(t)u^k(t)\,dt\right) \tag{12}$$

For accuracy analysis, we consider the following criterion (equation (13)). The optimal control (9) has the desirable accuracy when for a given positive constant ε, the following condition holds:

$$\left|\frac{J^k - J^{k-1}}{J^{k-1}}\right| < \varepsilon. \tag{13}$$

If the tolerance error bound $\varepsilon > 0$ is chosen small enough, then the kth order optimal control law will be very close to the optimal control law $u^*(t)$, the value of the quadratic performance index in equation (12) will be very close to its optimal value J^*, and the boundary state conditions will be satisfied tightly.

The convergence analysis of the projection method is given in the following theorem. The proof was derived in Pulova (2009).

Theorem 4. Let the sequence $u^k = \left(u_0^k, u_1^k, \dots, u_{N-1}^k\right)$, $u_i^k \epsilon\, K$, $K \subseteq \mathbb{R}^m$, $k = 0,1,\dots$, is obtained from applying the projection method. There exists an accumulation point $\tilde{u}$ of this sequence and a piecewise constant function defined by $\tilde{u}(t) \equiv \tilde{u}_i$ for $t \in [t_i, t_{i+1})$. Also, for $u^*(t) \in T^*$ where $T^* = \{u(.)| < Z(u(.)), v(.) - u(.) > \geq 0, v(.) \epsilon\, K\}$ we have:

$$\|u^* - \tilde{u}\|^2 \leq O(h), \tag{14}$$

where $||u - v|| = \max_{0 \leq i \leq N-1} |u_i - v_i|$.

4. Simulation results

This section will test the method on an example and a case study.

4.1. An example

Consider the following OCP Pulova (2009):

$$\begin{aligned} &min \quad \int_0^1 [x^2(t) + u^2(t)]dt \\ &s.t. \quad \dot{x} = -ax(t) + Bu(t) \\ &\qquad\quad x(0) = 1 \\ &\qquad |u| < 1 \end{aligned} \tag{15}$$

The analytical optimal solution to this problem is

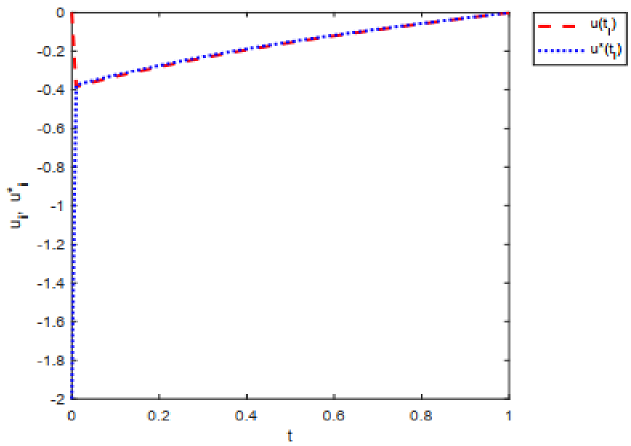
$$u^* = c_1 e^{r_1 t} + c_2 e^{r_2 t}$$

where,

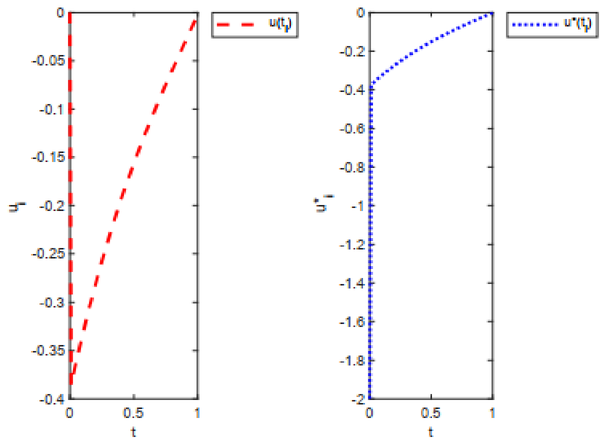
$$r_1 = \sqrt{a^2+1}, \qquad r_2 = -\sqrt{a^2+1},$$

$$c_1 = \frac{1}{r_1 - a - (r_2 - a)e^{r_1 - r_2}}, \qquad c_2 = \frac{1}{r_2 - a - (r_1 - a)e^{r_1 - r_2}}.$$

We solve the problem by setting $a = 1$, $N = 100$, $h = 0.01$, and $t_i = ih$ for $i = 0,1,\ldots,N$. The transient behaviour of the optimal solution of the control variable is given in Figure 1. As you can see we choose the initial value from out of the feasible region ($u_0 = -2$) and the solution converges to the optimal solution. This is the advantage of using the projection method.



(a) Trajectory of $u(t_i)$ and u^*.



(b) Trajectory of $u(t_i)$ and u^*.

Figure 18. Trajectories of control vector

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4.2. Case study: production planning in reverse logistics system

Finished products and manufacturing plants are some elements of the production system in SC, and there are other manufacturing plants. They produce work in process and finished products and hold them in warehouses. So, they need to plan and control production and inventories. Isolated planning and control by different manufacturers increase inventories in them, and then they must plan and control integratory. The application in management science consists of the control of dynamics, i.e., continuous or discrete-time systems are such systems. The difference between these systems depends on whether time varies continuously or discretely. These systems are an important research area in management (Sethi and Thompson, 2000; Kistner and Dobos, 2000; Tang and et al., 2021; Vicil, 2021). The exciting topic in this area is the application of optimal control theory to the product inventory system.

Here, we are going to solve the OCP with the proposed method. The OCP was modelled based on production planning in a three-stock reverse logistics system with deteriorating items (11). Assume some definitions from Hedjar et al. (2015) as follows:

$I_r(t)$: Inventory of remanufacturing at time t.
$I_m(t)$: Inventory of manufacturing at time t.
$I_t(t)$: Inventory of returned items at time t.
$u_r(t)$: Level of remanufacturing at time t.
$u_m(t)$: Level of manufacturing at time t.
$u_d(t)$: Level of disposal at time t.

From Hedjar et al. (2015), the control and the state vectors are as $u(t) = \left(\Delta\, u_m(t).\ \Delta u_r(t).\Delta u_d(t)\right)^T$ and $x(t) = \left(\Delta\, I_m(t).\ \Delta I_r(t).\Delta I_t(t)\right)^T$, respectively, where

$\Delta\, I_m(t) = I_m(t) - \widehat{I_m(t)}$
$\Delta\, I_r(t) = I_r(t) - \widehat{I_r(t)}$
$\Delta\, I_t(t) = I_t(t) - \widehat{I_t(t)}$
$\Delta\, u_m(t) = u_m(t) - \widehat{u_m(t)}$
$\Delta\, u_r(t) = u_r(t) - \widehat{u_r(t)}$
$\Delta\, u_d(t) = u_d(t) - \widehat{u_d(t)}$

Also, "$\hat{.}$" shows the target value of the variables. The following OCP is given in Hedjar et al. (2015):

$$\min \mathrm{J} = \frac{1}{2}\int_0^{t_f} [q_m\Delta\, I_m(t) + q_r\Delta\, I_r(t) + q_t\Delta I_t(t) + r_m\Delta u_m(t) + r_r\Delta u_r(t) + r_d\Delta u_d(t)]$$

$$s.t.\ \frac{d(\Delta I_m(t))}{dt} = \Delta\, u_m(t) - \theta_m\Delta I_m(t)$$

$$\frac{d(\Delta I_r(t))}{dt} = \Delta\, u_r(t) - \theta_r\Delta I_r(t)$$

$$\frac{d(\Delta I_t(t))}{dt} = -\Delta\, u_r(t) - \Delta u_d(t)$$

$$\Delta I_m(0) = I_m^0,\quad \Delta I_r(0) = I_r^0,\ \Delta I_t(0) = I_t^0.$$

The OCP can be restated as the following matrix form:

$$\min \quad \mathrm{J} = \frac{1}{2}\int_0^{t_f} (\mathrm{x}^{\mathrm{T}}(\mathrm{t})\mathrm{Q}\mathrm{x}(\mathrm{t}) + \mathrm{u}^{\mathrm{T}}(\mathrm{t})\mathrm{R}\mathrm{u}(\mathrm{t}))\mathrm{dt}$$

$$s.t.\quad \dot{\mathrm{x}} = \mathrm{A}(\mathrm{t})\mathrm{x}(\mathrm{t}) + \mathrm{B}(\mathrm{t})\mathrm{u}(\mathrm{t})$$

$$\mathrm{x}(0) = \mathrm{x}_0$$

$$|u| \leq 10.$$

where,

$$Q = \begin{bmatrix} q_m & 0 & 0 \\ 0 & q_r & 0 \\ 0 & 0 & q_t \end{bmatrix},\quad R = \begin{bmatrix} r_m & 0 & 0 \\ 0 & r_r & 0 \\ 0 & 0 & r_d \end{bmatrix},\quad A = \begin{bmatrix} -\theta_m & 0 & 0 \\ 0 & -\theta_r & 0 \\ 0 & 0 & 0 \end{bmatrix},$$

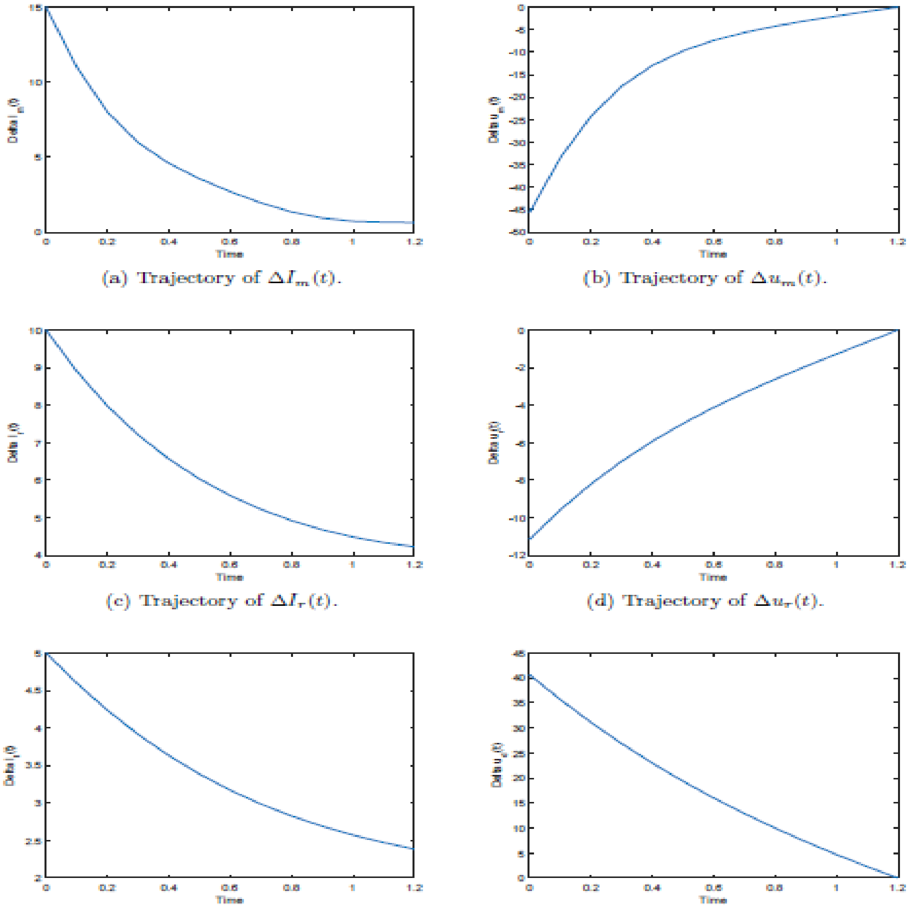
$$B = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & -1 & -1 \end{bmatrix},\quad x_0 = \begin{bmatrix} \Delta I_m(0) \\ \Delta I_r(0) \\ \Delta I_t(0) \end{bmatrix}$$

Now, assume the given values in Table 1 from Hedjar et al. (2015).

Table 5. The given parameters and initial states

Parameter	value	Parameter	value	Parameter	value	Parameter	value	Parameter	value
$\Delta I_m(0)$	15	q_m	1	θ_m	0.01	r_m	0.1	r_d	0.3
$\Delta I_r(0)$	10	q_r	2	θ_r	0.02	r_r	0.2	t_f	1.2
$\Delta I_t(0)$	5	q_t	3						

Employing the proposed method gives Figure 2 depicting the optimal control and state variables trajectories.



(a) Trajectory of $\Delta I_m(t)$. (b) Trajectory of $\Delta u_m(t)$.

(c) Trajectory of $\Delta I_r(t)$. (d) Trajectory of $\Delta u_r(t)$.

(e) Trajectory of $\Delta I_l(t)$. (f) Trajectory of $\Delta u_d(t)$.

Figure 19. Trajectories of state and control vectors

The solutions tend to be zero, similar to the obtained results in Hedjar et al. (2015). Hedjar et al. (2015) used the predictive control approach for solving the presented OCP.

5. Conclusion

This article presented an iterative approach to solving the linear quadratic optimal control problem with bounded control variables. The challenges of the optimal control problems were the bounded control variables so that conventional techniques could not be applied. The iterative approach presented in this paper guaranteed the uniform convergence of the solution for the problem. We applied the projection function to construct the approximation method. Employing the projection function had other advantages: we could select the initial value from out of the region. Finally, a case study on production planning in a reverse logistics system with deteriorating items was given and solved based on the proposed method.

Disclosure statement

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

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Evaluation Commercialization Challenges and Resolutions in SMEs Using ML-FCM (Case study: Sanat Prozheh Toos)

Vahideh Bafandegan Emroozi[a], Ali Faezian[b]*, Kambiz Seffati[c], Hossein Ebrahimi[d], Babak Dadakhani[c]

[a] *Department of Management, Faculty of Economics and Administrative sciences, Ferdowsi University Of Mashhad, Mashhad, Iran.*
[b] *Food Machineries Department, Research Institute of Food Science and Technology, Mashhad, Iran.*
c South Pars Fifth Refinery, Asalouye, Iran.
d South Pars seventh Refinery, Asalouye, Iran.

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ABSTRACT

Commercialization of innovative products in small and medium-sized enterprises (SMEs) faces many challenges. In this study, the factors related to the existing challenges and resolutions are identified with the help of the multi-layer fuzzy cognitive mapping (ML-FCM) method. The most effective criterion is introduced by examining the centrality. Also, the challenges and the existing resolutions to overcome these challenges are specified, and the most effective ones are determined. The present study addresses the practical experience of Sanat Prozheh Toos Company, which operates in the design and production of mechanical noise pollution control equipment (e.g., Silencers). The data is collected based on the organization's documents and experts' opinions. Research findings confirm that among the challenges of commercialization of innovative products associated with the case study, management challenge has the highest degree of effectiveness and centrality; moreover, among the ways of overcoming these challenges, organizational integration has the highest degree of centrality. Thus, the findings provide policy and management suggestions for SMEs policymakers and managers in commercializing advanced technologies.

Keywords

Small and medium-sized enterprises (SMEs), Silencer, Noise pollution, Commercialization, Multi-layer fuzzy cognitive mapping method (ML-FCM).

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****Corresponding author***
Email: a.faezian@rifct.ac.ir

1. Introduction

Due to the rapid growth of technologies and the reduction of the product life cycle, the commercialization problems of advanced and innovative products have been highlighted. Most companies have expanded their activities in this field (Khalil Zadeh et al., 2017). Commercialization is the process by which knowledge and technology are transferred from universities and research centres to new industries and businesses. This complex process is influenced by many infrastructural, technological, social, political, and historical factors. New and innovative commercializing technologies face many obstacles in this field due to financial reasons and the lack of understanding of optimal organizational strategies (Dehghani, 2015). Despite considerable investments in this field, the rate of commercialization of technologies is reported to be lower than expected (Khalil Zadeh et al., 2017). Examining the commercialization process of various innovations shows that in the initial stages of commercialization development, the organization faces challenges that result in the highest rate of failure and stoppage. Organizations that pass this stage can obtain the produced value and create wealth.

In this research, we seek to identify and determine the most practical challenges of passing through the stage of the growth process called the valley of death and identify the solutions and capabilities of the organization to give this stage. The valley of death is considered a factor in the survival of companies and organizations when a technology-oriented and innovative business is trying to commercialize and earn money commercially. Barriers due to financial conditions, changing market needs, and focusing on technical and ignoring the management aspects of the business are created (Frank et al., 1996; Hudson and Khazragui, 2013; Ellwood et al., 2022; Rajabi et al., 2022). Therefore, in response to many structural, managerial, financial, and marketing challenges, policymakers and researchers in technology commercialization have provided resolutions to get out of these crises. Since the logic of science is different from commercialization, the transition from the stage of scientific research to the commercialization of technology must be managed to avoid obstacles. Researchers have provided various ways to help overcome these challenges.

This paper uses the multi-layered fuzzy cognitive mapping (ML-FCM) method to determine and identify the most critical factors in commercializing innovative products and resolutions to overcome these challenges of small and medium-sized enterprises (SMEs). The ML-FCM technique is one multi-criteria decision-making (MCDM) method that extended from the FCM technique (Roozkhosh and Kazemi, 2022). these methods help the decision-maker to assess all these criteria (Modares et al., 2022; Bafandegan Emroozi and Fakoor, 2023; Modares et al., 2023). Since a lot of criteria are involved in supplier selection, it is an MCDM technique. MCDM methods are used when the aim chooses the critical criteria among many options based on the desired outcome (Modares et al., 2021; Modares et al., 2023). MCDM methods are a reliable approach for obtaining the appropriate solution. Using MCDM techniques, criteria are comprehensively surveyed from the perspective of multiple, conflicting, and interactive factors, and those that do not provide the minimum level of utility are removed from the process due to low importance in prioritization (Bafandegan Emroozi et al., 2022; Modares et al., 2023). When there are many criteria in making a decision and the decision-makers are confused about the options that must meet the criteria, one of the best ways is to compare the options and choose the best one and make a decision in the choice (Farimani et al., 2022; Modares et al., 2023; Roozkhosh et al., 2022).

The case study in this paper is Sanat Prozheh Toos Company, which designs and manufactures mechanical pollution and noise control equipment. Since the company is small and the vision and mission are based on innovation and have high research, and development activities, it has been chosen as the case study in this research. The rest of the paper is organized as follows. Section 2 describes the literature review of the subject. Section 3 discusses the research process. The findings are presented in Section 4. The conclusion is given in Section 5.

2. Literature review

2.1. The valley of death in technology commercialization

For the first time, the meaning and concept of Death Valley were proposed by Bruce Merrifield. This definition first referred to the challenges in transferring technologies in the agricultural industry. In the subsequent years, this concept was used to describe the gap between scientific research and the commercialization of products in organizations (Markham et al., 2010). The valley of death represents the gap between the research stage and developing a new product. Technology start-up companies go through such challenges in the innovation process, from the idea generation stage to the commercialization of the product**.**

(Klitsie et al., 2019; Dean et al., 2022). Despite having a product or service prototype, a vast number of companies may fail to commercialize the product (Hudson and Khazragui, 2013). The results of previous research indicate that the significant commercialization problems in technology start-up companies can usually be categorized into four main areas. These four main areas are shown in Figure 1 (Pellikka and Virtanen, 2009).

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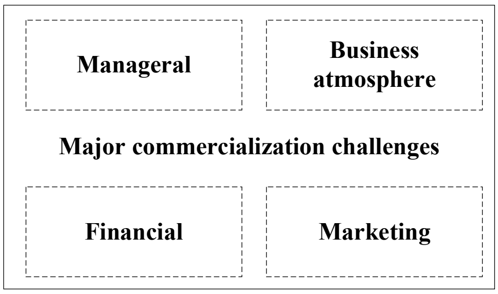

Figure 20. Commercialization problems

2.2. Multi-Layer fuzzy cognitive methods (ML-FCM)

ML-FCMs can be argued as an extended form of FCMs by using sub-FCMs. Sub-FCMs are smaller FCMs organized into layers that extend and decompose some concepts in the immediately higher layer (Fig. 1) (Christoforou and Andreou, 2017). This makes it possible to get a more detailed model and account for different levels of performance and decision-making in a single framework.

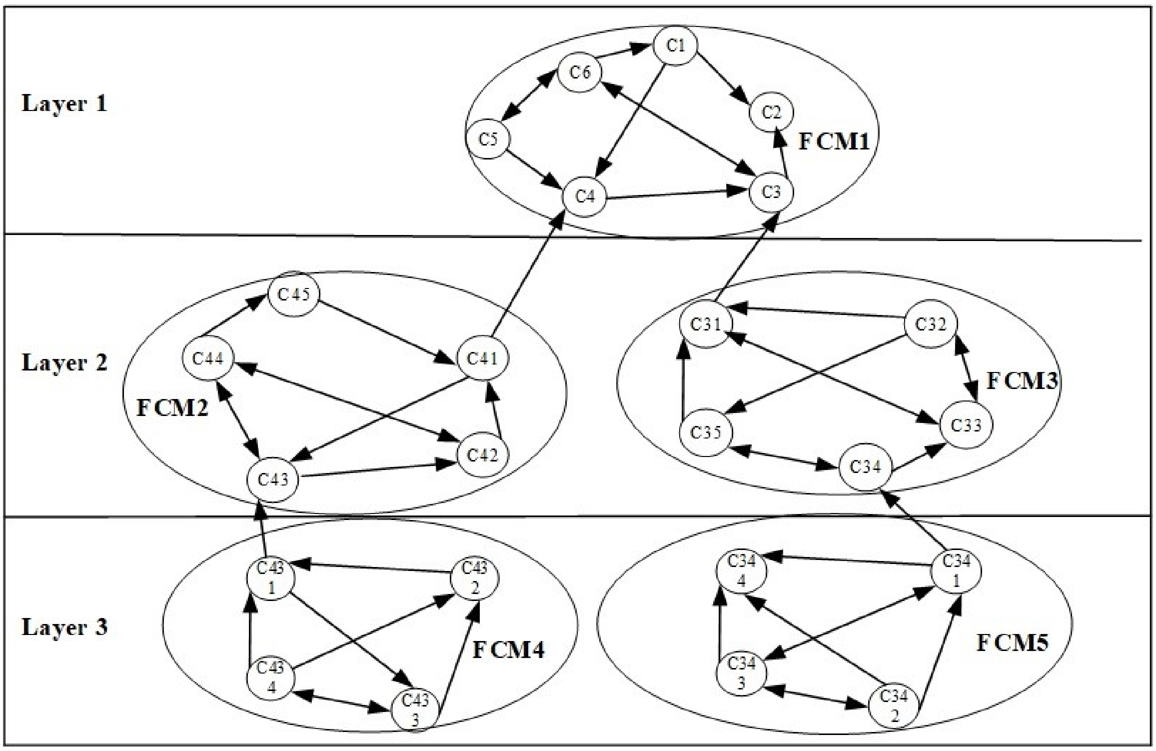

Figure 21. Example of a ML-FCM representation with three layers

ML-FCMs have been used to model complex systems in several scientific fields in recent years, as they allow the analysis of system parameters at higher specificity levels (Roozkhosh and Motahari). A ML-FCM framework was developed and applied to represent and simulate the cloud adoption decision problem (Christoforou and Andreou, 2017).

3. Research process

The research steps are shown in Figure 3.

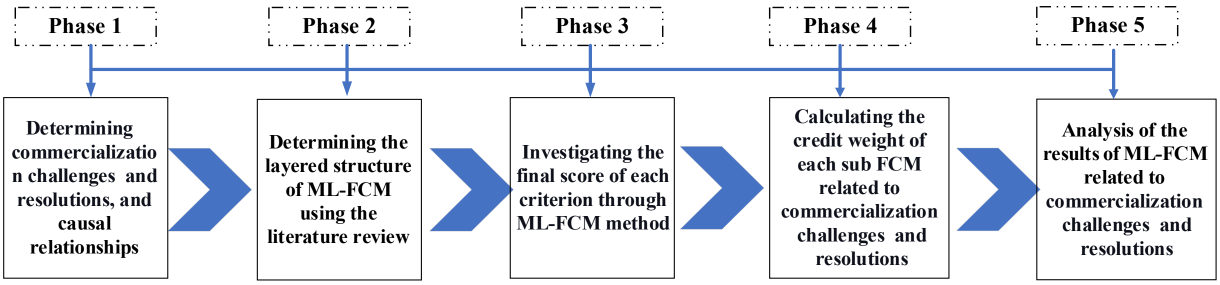

Figure 22. Research steps

3.1. Step 1: Determining commercialization challenges and resolutions, and causal relationships

At this stage, the challenges that exist on the way to the commercialization of innovative products are identified, and the causal relationships between these commercialization-inhibiting factors are collected based on the opinion of experts. Solutions to get out of these challenges are also collected based on previous research and experts' opinions, and causal relationships between the factors to get out of the challenges are also determined.

3.1.1. *Constructing the matrix of pairwise comparisons and weights vector at each level*

In this step, the relative weight of each component and sub-components is obtained through experts and the group pairwise comparisons matrix. ML-FCM graphs provide either the interviewee or modeler having the ability to give additional insights, concepts, and beliefs about a specific domain. Furthermore, the interdependencies and interrelations of criteria are also specified (Dickerson and Kosko, 1994; Palmer and Bolderston, 2006; Christoforou et al., 2017; Iraji, 2019).

3.2. Step 2. Determining the layered structure of ML-FCM using the literature review

Tables 1 and 2 show the FCMs of each layer and their respective concepts associated with challenges and resolutions, respectively. The concepts were selected based on a literature review on challenges and their solutions in connection with commercialization innovation products. For example, FCM 1 concepts represent total challenges. FCM 2 concepts represent management, FCM 3 concepts represent the business atmosphere and legal requirements, FCM 4 concepts illustrate finance, FCM 5 concepts show marketing, and FCM 6 concepts represent human resources. Evaluation criteria are obtained by reviewing the literature, knowledge, experience of experts, and other appropriate methods.

Table 6.Layers, FCMS and concepts for commercialization challenges

	Layer	FCM	ID	Concepts	References
Challenges	Layer 1	FCM 1_c (Main FCM)	C1	Managerial	
			C2	The business atmosphere and legal requirements	
			C3	Financial	
			C4	Marketing	
			C5	Human resource	
	Layer 2	FCM 2_c (Sub FCM)	C1	Managerial	
			C11	Uncoordinated planning	(Nevens, 1990; Abetti, 2004)
			C12	Lack of effective use of all facilities	(Sharma, 2005)
			C13	Lack of proper organization	(Nevens, 1990; Abetti and Rancourt, 2006)
			C14	Failure to use opportunities in the marketing	(Nevens, 1990; Kelley and Rice, 2002; Waters and Smith, 2002; Sharma, 2005)
			C15	Inability to identify strategic factors	
		FCM 3_c (Sub FCM)	C2	The business atmosphere and legal requirements	
			C21	Existence of specific legal requirements	(Kelley and Rice, 2002; Waters and Smith, 2002; Chen et al., 2011)
			C22	Lack of environmental monitoring	(Heydebrecket al., 2000)
			C23	Insufficient knowledge of the environment	(Abetti and Rancourt, 2006; Madrid-Guijarroet al.,, 2009)
		FCM 4_c (Sub FCM)	C3	Financial	
			C31	Lack of proper policies and facilities	(Heydebrecket al., 2000; Waters and Smith, 2002)
			C32	Allocation of excessive financial resources to (R&D)	(Kelley and Rice, 2002)
			C33	lack of investment for commercialization	(Madrid-Guijarroet al.,, 2009)
			C34	Limited access to financial resources	(White and Bruton, 2011)
		FCM 5_c (Sub FCM)	C4	Marketing	
			C41	Lack of continuity in the environmental scanning	(Daymon and Holloway, 2011)
			C42	A one-sided focus on the technical aspects of product development	(Heydebrecket al., 2000; Sharma, 2005)
			C43	Failure to understand the market potential of the product	(Sharma, 2005)
			C44	Starting marketing activities at the wrong time	(Hudson and Khazragui, 2013)
			C45	Ignoring the financial benefits of other people outside the organization is effective in marketing	(Khalil Zadeh *et al.*, 2017)
			C46	Receiving inaccurate information from competitors	(Pellikka and Virtanen, 2009)
		FCM 6_c (Sub FCM)	C5	Human resource	
			C51	Inexperience workforce	(Khalil Zadeh *et al.*, 2017)
			C52	Lack of identification of opportunities in the market	(Arvanitis et al., 2008)
			C53	Unskilled workforce	(Stander and Broadhurst, 2021)

Table 7. Layers, FCMS and concepts for commercialization resolutions

	Layer	FCM	ID	Concepts	References
Resolutions	Layer 1	FCM1$_r$ (Main FCM)	C1	Innovation	
			C2	Organization integrity	
			C3	Adjustment	
	Layer 2	FCM 2$_r$ (Sub FCM)	C1	Innovation	
			C11	Adequate and appropriate allocation of resources to innovative activities	(Cooper, 2011; Dattaet al., 2013; Datta et al., 2015)
			C12	Providing new and creative ideas	((Cooper, 2011)
			C13	Providing innovations fits the target market	(Khalil Zadeh *et al.*, 2017)
			C14	Making improvements on past products to suit the target market	(Datta et al., 2015; Khalil Zadeh *et al.*, 2017)
			C15	Ability to identify environmental opportunities	(Chiesa and Frattini, 2011)
			C16	Creating a balance between risks and benefits	(Arvanitis et al., 2008)
		FCM 3$_r$ (Sub FCM)	C2	Organization integrity	
			C21	Common work procedures	(Kotha et al., 2013)
			C22	Integrated problem-solving in all units of the organization	(Madrid-Guijarro et al.,, 2009; Khalil Zadeh *et al.*, 2017)
			C23	Common vision and consensus regarding the mission of the organization	(Lichtenthaler, 2005; Cooper, 2011; Stander and Broadhurst, 2021)
		FCM 4$_r$ (Sub FCM)	C3	Adjustment	
			C31	Adaptability to the market	(Stenroos and Lehtimäki, 2013)
			C32	Identifying new opportunities to offer innovative products	(Khalil Zadeh *et al.*, 2017)
			C33	Adjustment to new policies	(Jung et al.,2015; (Khalil Zadeh *et al.*, 2017)

3.3. Step 3. Investigating the final score of each criterion through the ML-FCM method

3.3.1. Constructing the adjacency matrix

A comparison scale has been chosen to compare the relative importance of the components. This step requires setting criteria for decision-making (Hejazi and Roozkhosh, 2019). The fuzzy comparison scale is included the levels presented in Table 3.

Table 8. Comparison scale levels

Fuzzy number	Linguistic variables
(0.8,0.9,1)	Positive very big (PVB)
(0.6,0.75,0.9)	Positive big (PB)
(0.3,0.5,0.7)	positive medium (PM)
(0.1,0.25,0.4)	positive small (PS)
(0,0.1,0.2)	Positive very small (PVS)
(-0.1, -0.2,0)	Negative very small (NVS)
(-0.4, -0.25, -0.1)	Negative small (NS)
(-0.7, -0.5, -0.3)	Negative medium (NM)
(-0.9, -0.75, -0.6)	Negative big (NB)
(-1, -0.9, -0.8)	Negative very big (NVB)

3.3.2. Adjacency matrix

The values of the criteria are determined concerning each other, which are quantified by the table of fuzzy numbers and are diffused by equation 1:

$$R_{ij}^{*k} = \frac{u + 4m + l}{6} \tag{1}$$

After drawing the cognitive mapping and coding the adjacent matrix, the model is executed to see where the system will converge. If this happens, they reach steady values, and their state will not change. These calculations are obtained using an automated neural network.

$$A_i^t = f(\sum_{\substack{j=1 \\ j \neq i}}^{N} A_j^{t-1} w_{ij} + A_j^{t-1}) \tag{2}$$

In equation 2, N is the total number of variables, A_j^{t-1} which is the value c_j at the time $t-$. w_{ij} is the effect of c_i on c_j . (c_i and c_j are the factors.). F(.) is a transfer function, which gives values of concepts in the range [0 1] and is formulated as follows:

$$f(x) = \frac{1}{1 + e^{-mx}} \tag{3}$$

Where m is a positive real number, and x is the value $A_i^{(k)}$ at the equilibrium point. As shown in equation 3, a sigmoid function is a threshold function that converts the result to a number in the interval [0,1]. Network convergence makes it possible to predict the future stable state of the system and make the right decisions. The inference and simulation process uses a bottom-up approach from layer 2 to layer 1. First, the inference process is performed independently in the sub-graphs of layer 2. Then the inference process is performed in layer 1, using the equilibrium point results from layer 1 as the input activation levels of the transmission concepts.

3.4. Step 4. Calculating the credit weight of each sub-FCM related to commercialization challenges and resolutions

The matrix obtained from the third stage is considered the input of fuzzy cognitive mapping and UCINET software. The criteria' degree of input, output, and centrality are specified. The absolute value of the inputs to each criterion indicates the effect value. Also, the absolute value of the output of each criterion is the influence value. The sum of the input and output degrees of each criterion indicates the centrality of that criterion. The effect value (input flow), influence (output flow), and degree of centrality for challenge and resolution criteria are calculated using the adjacency matrix in each node in Tables 3 and 4, respectively. Finally, a cognitive map of the main performance appraisal criteria is drawn. Edges indicate the direction and extent of the impact of one criterion on another. Figures 4 and 5 illustrate the ML-FCM model (i.e., main FCM) for commercialization challenges and resolutions for innovation products using data and following the steps described in the previous section, respectively.

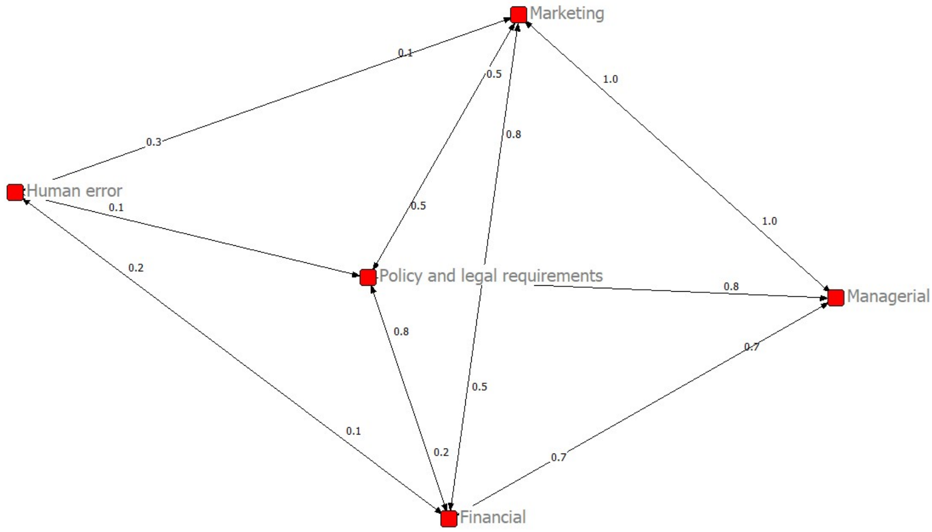

Figure 23. Investigating the impact of criteria associated with challenges FCM 1_c

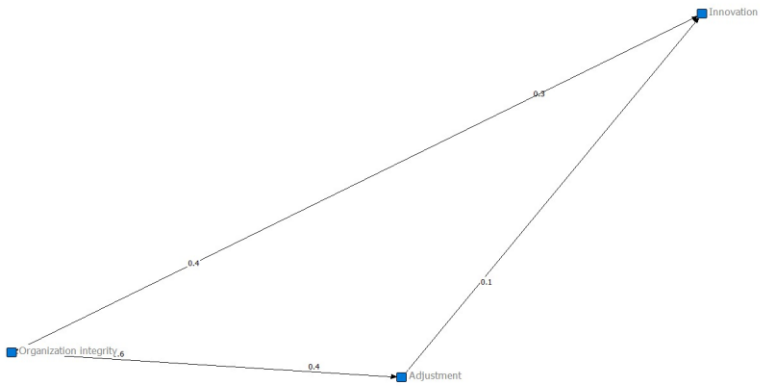

Figure 5. Investigating the impact of criteria associated with resolutions FCM 1_r

Moreover, the criteria relationships and effect relations between nodes in each sub-FCM are calculated. Each node represents a variable in these figures, and the input and output values are marked with numbers on the vectors. Figure 6 shows the ML-FCM model (i.e., sub-FCM of C4) for commercialization challenges associated with marketing factor through data and following the steps described in the previous section. It is calculated in the same way for other sub-layers, including managerial, the business atmosphere and legal requirements, financial and human resources.

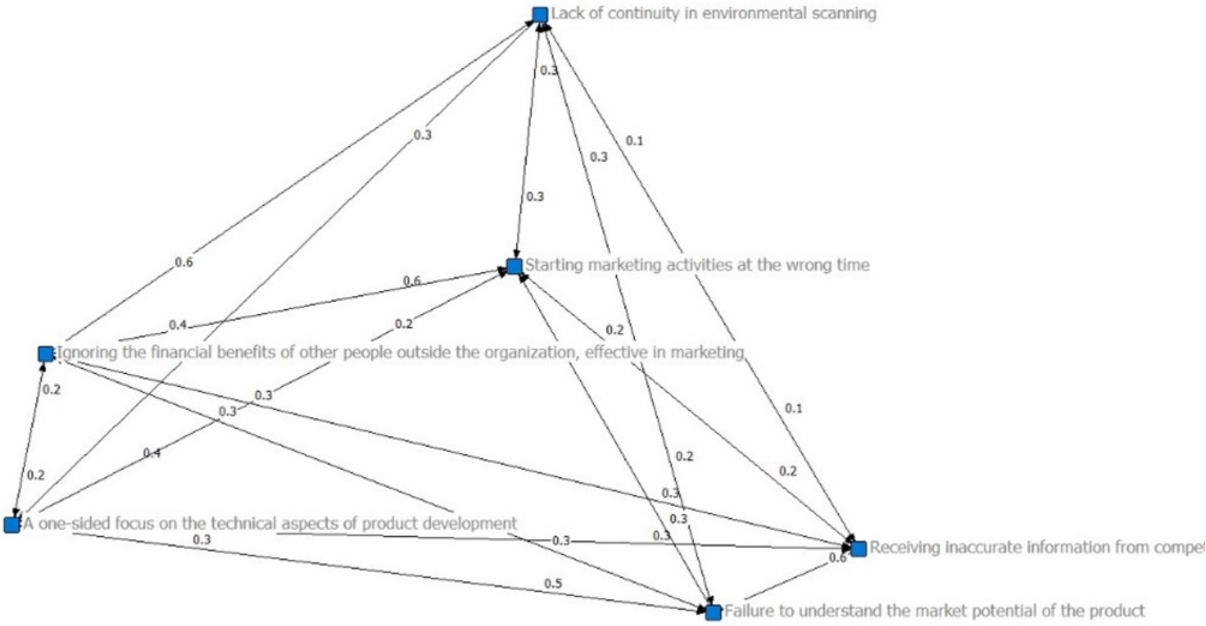

Figure 6 - Investigating the impact of sub-criteria associated with challenges sub FCM of C4 (i.e., Marketing)

Figure 7 shows the ML-FCM model (i.e., sub-FCM of C1) for commercialization resolutions related to innovation factor through data and following the steps described in the previous section. Other sub-layers, including organization integrity and adaptation likewise are calculated.

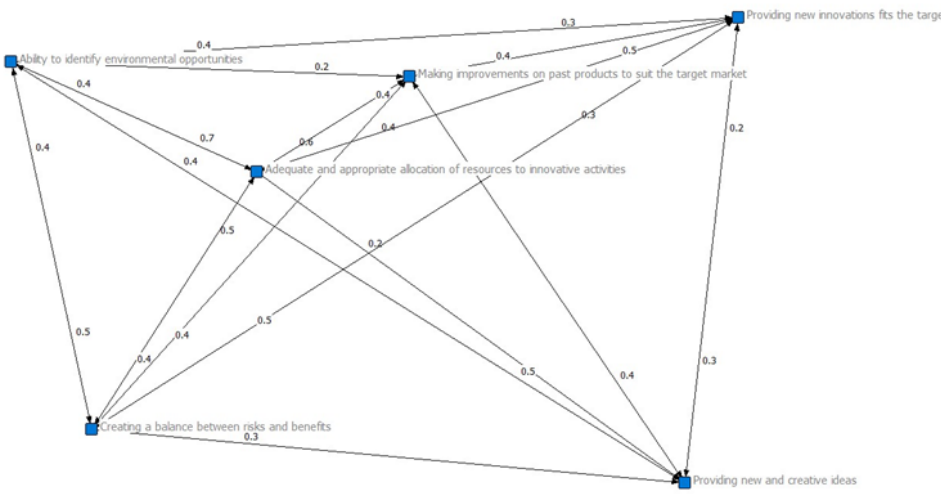

Figure 7- Investigating the impact of sub-criteria associated with challenges sub FCM of C1 (i.e., Innovation)

3.5. Step 5. Analysis of the results of ML-FCM related to commercialization challenges and resolutions

The main results of this paper are the framework of the ML-FCM model for challenge and resolution factors and the convergence values of the concepts in each FCM after running the simulations. Figures 4 and 5 illustrate the ML-FCM model through data and follow the steps described in the previous section. The model construction is analyzed by calculating the sum of the weights of incoming (effect value) and outgoing (influence) edges to node i and total value (centrality), and are calculated as follows:

$$Value_{in}(i) = \sum_{j} \omega_{ji} \tag{4}$$

$$Value_{out}(i) = \sum_{j} \omega_{ij} \tag{5}$$

$$Total\,Value(i) = Value_{in}(i) + Value_{out}(i)$$

Centrality for the challenge and resolution criterion are shown in Tables 3 and 4, respectively. Based on the results of Table 3, each FCM of the model has density values above the medium complexity threshold, so it can be concluded that the ML-FCM model for the commercialization of innovative products in this work is a highly complex structure.

Table 9. Criteria value of each FCM and sub-FCM

	Layer	**FCM**	**ID**	**Concepts**	**Value (in)**	**Value (out)**	**Total value** (Centrality)
Challenges	Layer 1	FCM1 (Main FCM)	C1	Managerial	2.5	2.4	4.9
			C2	The business atmosphere and legal requirements	2.1	1.5	3.6
			C3	Financial	1.5	2.5	4
			C4	Marketing	2.4	2.3	4.7
			C5	Human resource	0.5	0.3	0.8
	Layer 2	FCM2 (Sub FCM of C1)	C11	Uncoordinated planning	2.3	2.4	4.7
			C12	Lack of effective use of all facilities	2.2	0.9	3.1
			C13	Lack of proper organization	2.2	1.6	3.8
			C14	Failure to use opportunities in the marketing	1.9	2.1	4
			C15	Inability to identify strategic factors	0.4	0.3	0.7
		FCM3 (Sub FCM of C2)	C21	Existence of specific legal requirements	0.4	0.3	0.7
			C22	Lack of environmental monitoring	0.7	0.3	1
			C23	Insufficient knowledge of the environment	0.4	0.1	0.5
		FCM4 (Sub FCM of C3)	C31	Lack of proper policies and facilities	0.9	0.6	1.5
			C32	Allocation of excessive financial resources to (R&D)	0.6	0.9	1.5
			C33	lack of investment for commercialization	0.4	0.6	1
			C34	Limited access to financial resources	0.9	0.7	1.6
		FCM5 (Sub FCM of C4)	C41	Lack of continuity in the environmental scanning	1	0.7	1.7
			C42	A one-sided focus on the technical aspects of product development	1.5	1.2	2.7
			C43	Lack of understanding of the market potential of the product	1.1	1.8	2.9
			C44	Starting marketing activities at the wrong time	1.6	1.3	2.9
			C45	Ignoring the financial benefits of other people outside the organization	1.2	1.4	2.6
			C46	Receiving inaccurate information from competitors	1.2	0.9	2.1
		FCM6 (Sub FCM of C5)	C52	Inexperience workforce	1.2	1.2	2.4
			C53	Unskilled workforce	1	1.3	2.3
				Lack of identification of opportunities in the market	1.1	0.9	2

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The highlighted rows in Tables 3 and 4 identify concepts of most importance in each FCM. These factors have the most significant impact on the commercializing of innovative products. The two most important concepts of the main FCM are managerial and marketing challenges. Furthermore, the two most important concepts of the main FCM are organization integrity and adaption resolutions.

Table 5. Criteria value of each FCM and sub-FCM

	Layer	FCM	ID	Concepts	Value (in)	Value (out)	Total value (Centrality)
Resolutions	Layer 1	FCM1$_r$ (Main FCM)	C1	Innovation	0.4	0.4	0.8
			C2	Organization integrity	1	0.7	1.7
			C3	Adaptation	0.4	0.7	1.1
	Layer 2	FCM 2$_r$ (Sub FCM of C1)	C11	Adequate and appropriate allocation of resources to innovative activities	2.4	2.2	4.6
			C12	Providing new and creative ideas	1.5	1.2	2.7
			C13	Providing innovations fits the target market	1.7	2	3.7
			C14	Making improvements on past products to suit the target market	1.4	1.4	2.8
			C15	Ability to identify environmental opportunities	1.2	2.1	3.3
			C16	Creating a balance between risks and benefits	1.4	1.9	3.3
		FCM 3$_r$ (Sub FCM of C2)	C21	Common work procedures	0.6	0.8	1.4
			C22	Integrated problem-solving in all units of the organization	0.5	0.6	1.1
			C23	Common vision and consensus regarding the mission of the organization	0.7	0.4	1.1
		FCM 4$_r$ (Sub FCM of C3)	C31	Adaptability to the market	0.5	0.3	0.8
			C32	Identifying new opportunities to offer innovative products	0.2	0.3	0.5
			C33	Adjustment to new policies	0.3	0.4	0.7

4. Finding

Table 4 shows the degree of effectiveness and the degree of centrality of the criteria for the commercialization of innovative products. Among the main FCM variables, management and marketing criteria play the most effect and centrality as the main factors of challenges in commercializing products in SMEs. In the second layer, all sub-FCM are considered, and the criteria with the highest degree of centrality are highlighted in each. Therefore, based on the obtained results, it can be concluded that the main challenges in the commercialization of innovative products are related to the study of management and marketing challenges. Uncoordinated planning, lack of understanding of the product's market potential, and starting marketing activities at the wrong time are considered the main sub-criteria in these challenges. Table 5 shows the degree of effectiveness and the degree of centrality of the criteria for the commercialization of innovative products. Among the main FCM variables, the criteria of adaption and organization integrity play the most significant effect and centrality as the leading solutions to overcome the challenges of product commercialization in SMEs.

5. Conclusion

Given the development of innovations and the process of commercial enterprises, the development of innovations within each company's ecosystem is different and should be examined separately. Therefore, considering the case study, the innovation ecosystem of noise pollution control products and services has faced many challenges across the valley of death. Owing to the increasing complexity and dynamics of the environment, analyzing and managing innovation development cannot be limited to the environment within the company. Therefore, the boundaries beyond and broader than the company should be considered, which includes the more diverse challenge. ML-FCM is a powerful soft-computing tool for modeling complex systems that allow for the extension and decomposition of concepts by applying a multi-layered grouping approach. For the significant purpose of this research, we examined a period in the innovation ecosystem development process, which is equivalent to passing from a knowledge ecosystem to a business ecosystem (valley of death). Based on the results obtained, the challenges in this research include five categories of management, policy, legal, financial, marketing, and personnel requirements.

Creating a series of capabilities brings about the potential to perform activities in the ecosystem and overcome these challenges. Based on this, three strategies of innovation, including integration, adaptability, and effective implementation, were introduced as strategies to overcome these challenges. Creating a series of capabilities brings about the potential to perform activities in the ecosystem and overcome these challenges. Based on this, three strategies of innovation, including organization integration, innovation, and adaption, were introduced as strategies to overcome these challenges. Analyzing the density and strength indicators in the model construction made it possible to validate the high network complexity and the importance of the concepts used to commercialize innovative products. Furthermore, the convergence of the concept vectors in the inference process confirmed the initial selection of the concepts in the main FCM and the sub-FCMs. This work can help managers better understand factors affecting commercialization innovation products and the quantitative relationships between decision variables and comprehensive performance. Future work will focus on considering a larger number of concepts and other transfer functions and learning algorithms.

Disclosure statement

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

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Leveraging the Potential of Soft Systems Methodology to Trigger Data Governance Policy-Making in the Banking Industry

Mohammadali Faezirad[a*] Abolfazl Khoshnevisan[b]

[a] *Industries Research Group, Institute for Trade Studies and Research (ITSR), Tehran, Iran.*
[b] *Faculty of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran.*

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ABSTRACT

A data governance policy is a foundational document providing instructions to manage data assets and organizational information effectively. Within the field of data governance, data access is one of the most important aspects of data management and includes considerations such as the extent of access, how to access data, access position, and data control and application. This research focuses on the banking industry, as its multiple stakeholders, diverse attitudes, and intangible aspects have created a problematic situation. To better understand and improve the current situation, soft systems methodology (SSM) provides a rich picture of the complex situation of data access in the bank, extracts key system definitions, and leads to a correct understanding of purposeful activities. After identifying these purposeful activities, a support policy for each set of activities is evaluated based on the literature in the field of data governance, specifically regarding data access. A mapping is established between activities and the fundamental principles of the data governance policy. One important innovation of this research is that, instead of directly utilizing SSM in the policy development process, it describes the situation and fundamental actions to provide the foundation for the policy. In conclusion, the data access problem has been identified as having various dimensions that can be grouped into six categories: data application, risk, processing, infrastructure, route, and access. These categories have been used to develop 13 support policy rules.

Keywords

Banking sector, Data access policy, Data governance, Data management, Soft systems methodology.

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****Corresponding author***
Email: faezirad@mail.um.ac.ir

1. Introduction

Over the last two decades, the word 'governance' has expanded and conquered new grounds and is now widely used (Micheli et al., 2020). In different realms of governance, data governance plays a prominent role in various organizations and is increasingly growing because the current trends keep up the pace. Data governance refers to the ownership of and controls over data management. Its objective is to increase the value of data assets in organizations and reduce relevant costs and risks (Abraham et al., 2019). Those data that are properly managed can be evolutionary and support sound decisions and measures (Reichental, 2023).

A proper governance program includes a governance committee or assembly that complies with a set of procedures and programs for implementing them, given that the cornerstone of organizational data governance is the policy of managing and governing data (Khairi, 2019). A data governance policy is a base document comprising instructions and compliance to ensure effective data asset and organisation information management (Eryurek et al., 2021). This policy has been deemed a reference source for regulatory expectations that provide guidelines on organizational measures in the data domain. In this respect, a comprehensive policy on data governance must support key aspects, including systems or procedures associated with raw data security and control, internal auditing by quality control staff, report and investigation of suspicious violation cases of data integration, discipline measures, staff training when outsourcing or interacting with outside corporations (Truong et al., 2017).

Data governance rules in policy documents comprised data access, usage, integration, integrity, provenance, retention, and archival policy (Eryurek et al., 2021; Reichental, 2023). Among these elements, *data access,* one of the most important aspects of data management, should be subject to governance rules. Data access, in brief, emphasizes who has access to what sort of data or what commitments must be provided to permit data access (Kerber, 2020). In other words, this aspect of governance incorporates the extent of access, how to access data, access position, and data control and application (Khatri and Brown, 2010).

In this respect, some mechanisms are required to ensure principled data sharing and provide the possibility for data sharing and blocking of data sharing if necessary (Janssen et al., 2020). To this end, specific frameworks for trustworthy data sharing should be established, and the corresponding rules in governance policy can be investigated. Successful solutions to the problem of data access require an inclusive set of complementary enablers. In this context, the capability to cooperate, standardization, and security are among the mentioned enablers, which is the proper analysis and design of a comprehensive data governance system (Kerber, 2020).

Regarding cooperability, data access is a subcategory of the mentioned system because governance is achieved by complying with a set of laws and rules and implementing them and developed through collaborations and cooperation among players and stakeholders. Moreover, through proper adherence to the security aspects of data access in the data governance system as well as efficient management of data, one can reduce possible dangers to a minimum and meet the requirements (Reichental, 2023).

The banking industry is one field that holds the issue of data access in high regard. Backed by the massive data centers of customers and the services they receive daily, the banking industry can produce big data. This issue has become more significant following the dominant spread of mobile phones in daily lives and other emerging technologies because most transactions and events in different cycles of banking services lead to big data (Bedeley, 2014). Even though the banking industry stands to benefit significantly from such a massive amount of data, it causes a series of challenges in the technology and governance layers since data access, especially banking data, is subject to the policy enforced, given that banks deal with vital data that require the highest level of privacy and security (Alhassan et al., 2019).

By considering the commercial banks and investigating the data access issue in such organizations, this paper points out a significant problematic situation regarding cooperability between players and stakeholders and data access security (Kerber, 2020). Upon studying the aspects and characteristics of the problem under scrutiny, it can be stated that the mentioned problematic situation is quite complex and unstructured in this research. Such issues are strategic and enjoy essential features. These features include multi-stakeholders, perspectives, multi-dimensions, conflict of or incomparable interests, and other intangible aspects, along with uncertainty (Mingers and Rosenhead, 2004; Mingers, 2011).

Table 1 shows that the current situation of common commercial banks is best characterized by complexity and non-structuring. In this table, among the set of problematic features, a description of data access problems in the banking industry is proportional to every feature in various situations. A profound understanding or analysis of the current situation has provided the insight given in the table, and it is required to analyse its various dimensions.

Table 10. Analysis of the problem in unstructured and ill-structured terms

The complexity of the structure of the problem	Description of the problem status in the case of the intended feature
Multi-stakeholders	The process of applying for data at the bank level requires the presence of players and stakeholders. Applicants generally constitute bank-led marketing units, bank holding companies, and partner companies in active ecosystems. Further to the above, servicing a wide spectrum of data applicants can be made possible by the unit management with the help of infrastructure provided by the IT management. This is while the acts enacted by the risk committee, along with their missions and instructions approved at the office of organizations & methods, lay the ground for such servicing.
Multi-perspectives	Data applicants often try to acquire the data and information they need while the owner or custodian of these data acts conservatively in presenting them. The problematic nature of the current situation is illustrated based on the convenience and extension aspects of data access about the risk of presenting data and in relation to the technical and operational aspects of data communication.
Intangible and uncertain aspects	Compatibility of a data application with current banking objectives and adaptability to the present rules and instructions are forms of uncertainty in the process of applying for data. Data governance must be flexible and viable enough to design various scenarios for every application to assess the rate, time, and approach required to respond to any data application. This perspective has not been considered in various data applications, so these applications would not enjoy data integration.

This study aims to provide the problem of data access with a structure based on the perceived situation given in Table 1. Since data access is part of governance and data governance requires a policy to determine key rules (Eryurek et al., 2021), this study focuses on giving weight or sense to the experiences gained from the data-access process based on a policy formation. Sense-making in human interaction with various systems presenting meaningful displays aims to ensure a deeper understanding or perception of complex matters (Pirolli and Russell, 2011). Therefore, the outcome of this research may portray a rich picture of the current situation and binding rules concerning policy formation relevant to data access in the data governance framework.

Given the significance of perception over complex situations, especially in the case of the problematic situation under study, this study has considered using a method for structuring the problem so that 'discovery', 'learning', and 'obligation' can be achieved. Governance data design requires distancing from conventional organisational data management (Khatri and Brown, 2010). This issue can make the current problem more complex and has motivated the authors of this study to turn to situation-improving methodologies to deal with this delicate problem rather than problem-solving methods. In other words, a shift from an optimization/normative paradigm to interpretive/learning paradigm occurs in this study.

2. Literature review

Governance is a broad field that has seen the use of several soft operational research methods. Scenario planning, soft system methodology, system dynamics, and strategic choice have

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frequently been used in governance models (Aliahmadi et al., 2022). Specifically, SSM has been reported as useful in data governance, corporate governance, energy governance, and security governance. This research focuses on developing governance policy, and thus the use of SSM in this area is highlighted. Soft system methodology has emerged as a useful tool in policy-making in governance. SSM is a process-oriented approach used to understand and manage complex situations. The approach involves using qualitative data and systems thinking to identify the different perspectives of stakeholders and create a shared understanding of the problem at hand.

Previous research has considered the use of soft system methodology in policy development. Azar et al. (2017) designed a model for policy-making based on SSM in the nanotechnology sector. Due to the complexity of nanotechnology commercialization policy-making and the role of human factors in it, SSM was used to create a rich picture of the policy-making problem and its CATWOE definitions. In the conceptual modeling of activities, some activities were directly allocated to policy-making, making it a conceptual model for policy-making for nanotechnology commercialization.

Similarly, Monavarian et al. (2020) used SSM as a tool to structure the issue of policy-making for electronic banking to overcome uncertainties and set a long-term plan to preserve the future position of this industry. The issue was modeled using a two-circle conceptual model, which included several steps for creating policy in the electronic banking sector. Therefore, the use of SSM in this research focuses on the activities involved in policy-making generation.

Furthermore, Sujono et al. (2023) proposed a soft-systems thinking approach based on social network analysis to map mineral and coal policies by analyzing the law and producing research novelty. SSM was used to reflect on the limitations in capturing the highly complex and problematic Mining Law research.

As evident in the reviewed articles, most of the efforts to use SSM in developing policy and policymaking are devoted to directly using definitions and conceptual models in the policy-making process. However, in this study, an attempt has been made to make the system's behaviour meaningful based on SSM, and then policies are extracted and developed based on the necessary actions.

On the other hand, few studies exist on using SSM in determining the governance policy. Prasetyo and Surendro (2015) utilized SSM to create a data governance model tailored to the organisation's specific requirements. SSM aims to find a suitable model for data governance by considering stakeholders' definitions and perspectives and considering models from DAMA, IBM, and other sources. Ultimately, they created an Effective Data Governance Model using a cycle that involves Planning, Coordinating, Implementation, and Monitoring. The goal is to ensure data governance aligns with each organisation's unique needs.

Limited studies have focused on using SSM directly for creating data governance policies, and previous models that employed SSM for governance did not utilize the methodology suggested in this research.

3. Methodology

In order to create an interpretive perspective on improving the current situation under study, Soft Systems Methodology (SSM) was employed. SSM is widely associated with interpretive/learning paradigms and helps the current 'thinking' on a given problem be well structured (Azar et al., 2019). Well-structured thinking represents an organized and flexible process based on a systematic perspective to deal with problematic situations or circumstances for which proper measures must be taken to make them more acceptable, clearer, and calmer (Checkland and Poulter, 2007). To put it differently, SSM is a learning system that seeks to compromise with the situation constraints and takes targeted actions to achieve improvement (Mingers and Rosenhead, 2001).

SSM implementation takes place in 7 stages, some of which are real-world, while others are conceptual (Checkland and Poulter, 2020). In the first stage, a problem is discovered in the real world and its situation is considered. Here, the objective is not to define a problem but to determine what we seek. In the second stage, the individuals involved in this situation and the structure of this problem are depicted in a rich picture. The third stage is the point of departure from the real world to the conceptual and systemic one, where the problem's root definition is given. Root definition describes an ideal system, its objectives, and the individuals involved and introduces influenced and influencing individuals. To create a root definition based on rich pictures, a well-known method named CATWOE is used. Owners use CATWOE in forming and formulating a root definition of the problem and the following dimensions characterize it:

- **Customers (C):** Who are the customers, stakeholders, and individuals that gain or lose?
- **Actors (A):** Who are the players and participants in the system?
- **Transformation process (T):** What inputs can be transformed into what outputs in this process?
- **World View (W):** What is the world-view basis of the system?
- **Owner (O):** Who has the power or authority to stop the system?
- **Environment-related factor (E):** What environment constraints must be considered in this system?

In this fourth stage (conceptual model formation), a conceptual model is designed through root definitions involving a diagram model of activities with related connections. In this model, targeted actions are defined by imperative verbs and are arranged based on their interdependence (Mingers and Rosenhead, 2001; Azar et al., 2019).

SSM performance measures investigated for system evaluation are summarized by three main criteria: efficacy, efficiency, and effectiveness. Efficacy emphasizes proper transformation and output creation as a result of a process. Efficiency refers to the minimum and best use of sources, and effectiveness represents the capacity to reach goals on higher levels in the long term (Checkland and Poulter, 2007).

The fifth, sixth and seventh stages involve comparing real-world and conceptual models, defining required variations for improvement and development, and programming for applying those variations. Given that the objective of creating these purposeful activities is the corresponding mapping of data governance policy, this study does not attempt to model via SSM; instead, the focus is to form a data-access policy from the set of data governance programs via SSM-based purposeful measures.

To develop a comprehensive data governance policy using SSM, it is essential to map each area of the policy to each activity in the SSM action plan. This approach ensures that all aspects of data governance are addressed in the policy and there is a clear understanding of how each area of the policy relates to the SSM process. The SSM action plan comprises several activities, including problem definition, analysis, feasibility, implementation, and monitoring. Each of these activities can be used to develop specific aspects of the data governance policy. For example, in the problem definition activity, it is essential to identify the data-related issues that must be addressed in the policy. This could include data quality, security, privacy, and compliance with relevant regulations.

According to the above, the policy can be formed based on the conceptual model of SSM. In other words, the base of every activity and its contextualizer constitute parts of the rules that support the literature-approved policy.

The current study has utilized the expertise of professionals and specialists in commercial banking to develop a rich picture and conceptual model. The methodology used in the research involves a qualitative approach that relies on collecting and analysing data from in-depth interviews with experts in the field. The experts were selected based on their experience and knowledge of commercial banking and were asked to provide insights and perspectives on the various components and dynamics of the industry in order to data access in the data governance area. Through this process, a rich picture and conceptual model were developed that provide a comprehensive understanding of the data access of commercial banks and their various components. The rich picture provides a visual representation of the various components and their interrelationships, while the conceptual model offers a more abstract representation of the industry that highlights key concepts and relationships between them.

4. Findings in the data governance area

4.1. SSM components in the redefinition of data access problem

4.1.1. A rich picture of the problem

Creating a rich picture of the problem is an indirect attempt to access the leading establishments or institutions, structures, and perspectives in the current situation and ongoing processes that help better recognize the problem (Checkland and Poulter, 2007). The rich picture of the problem under study includes its engaged and effective roles and the association between them based on communication type (interactions, opinions, or data & information transfer) is depicted in Figure 1.

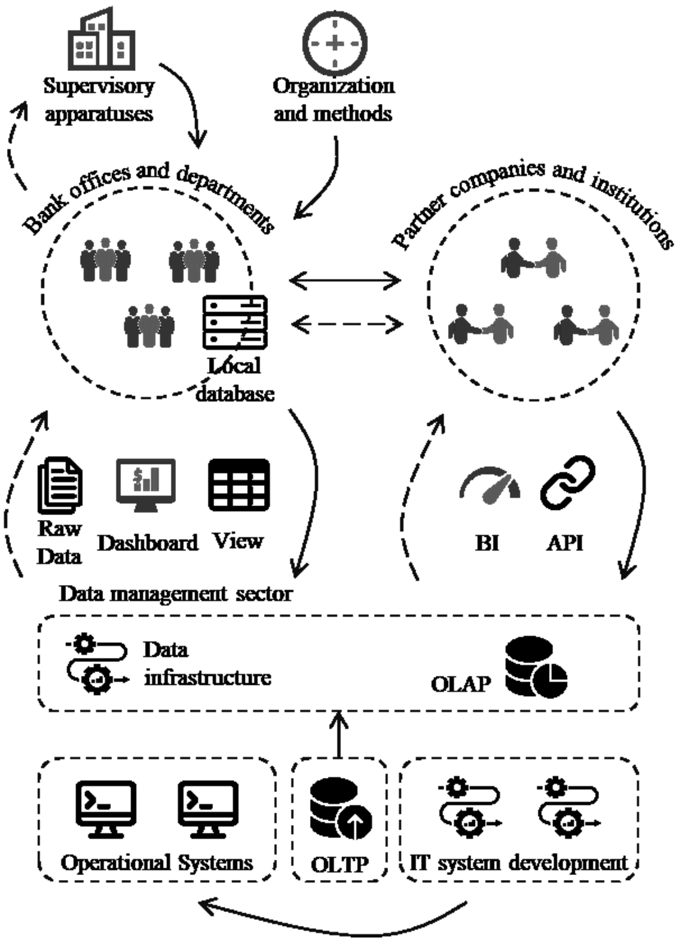

Figure 24. The rich picture of the data access and flow described in this section

4.1.2. CATWOE definitions

CATWOE includes effective elements in transfer activities and system objectives (Checkland and Poulter, 2020). These elements are separately expressed in the following to shed light on the components of the problem under study. Table 2 presents the CATWOE definitions.

Table 11. Definition of CATWOE components for the studied problem

Item	Definition
C (Customers)	1. Bank divisions 2. Subsidiaries 3. Partner companies 4. Dominant or supervisory institutions 5. Bank customers
A (Actors)	1. Data management department 2. IT Office 3. Risk office 4. Organizations & methods Office
T (Transformation process)	The input “data requirement” under the transformation process is transformed into the output “satisfied requirement through data access”.
W (World view)	1. Data access brings about valuation. 2. Data access control reduces the security risk and reporting burden. 3. Obviating the need for data is directly linked to the context of data and the way to access them.
O (Owner)	1. CEO 2. Data management committee
E (Environment Constraints)	1. Dominant laws and reports resulting from state and supervisory apparatuses. 2. Constraints result from collaboration with extra-banking companies through platforms and other interactive contexts

4.1.3. Root definition

According to Checkland and Poulter (2007), the enhancement formula for root definition is called PQR, which involves “applying P through Q to achieve R as a goal”. Accordingly and based on the definitions of CATWOE components, one can express the root definition of this research as follows: “Data governance system provides data access for all divisions and stakeholders through safe, efficient, application-friendly methods so that valuation concerning job tasks throughout the bank will increase, leading to the development of banking services and products.”

4.1.4. Conceptual model of activities

The intended conceptual model comprises purposeful activities of the system that must form in the framework of fundamental definitions and based on logical dependencies. Based on the earned recognition and CATWOE definitions, this problem achieves a set of activities compliant with the root definition, as shown in Figure 2.

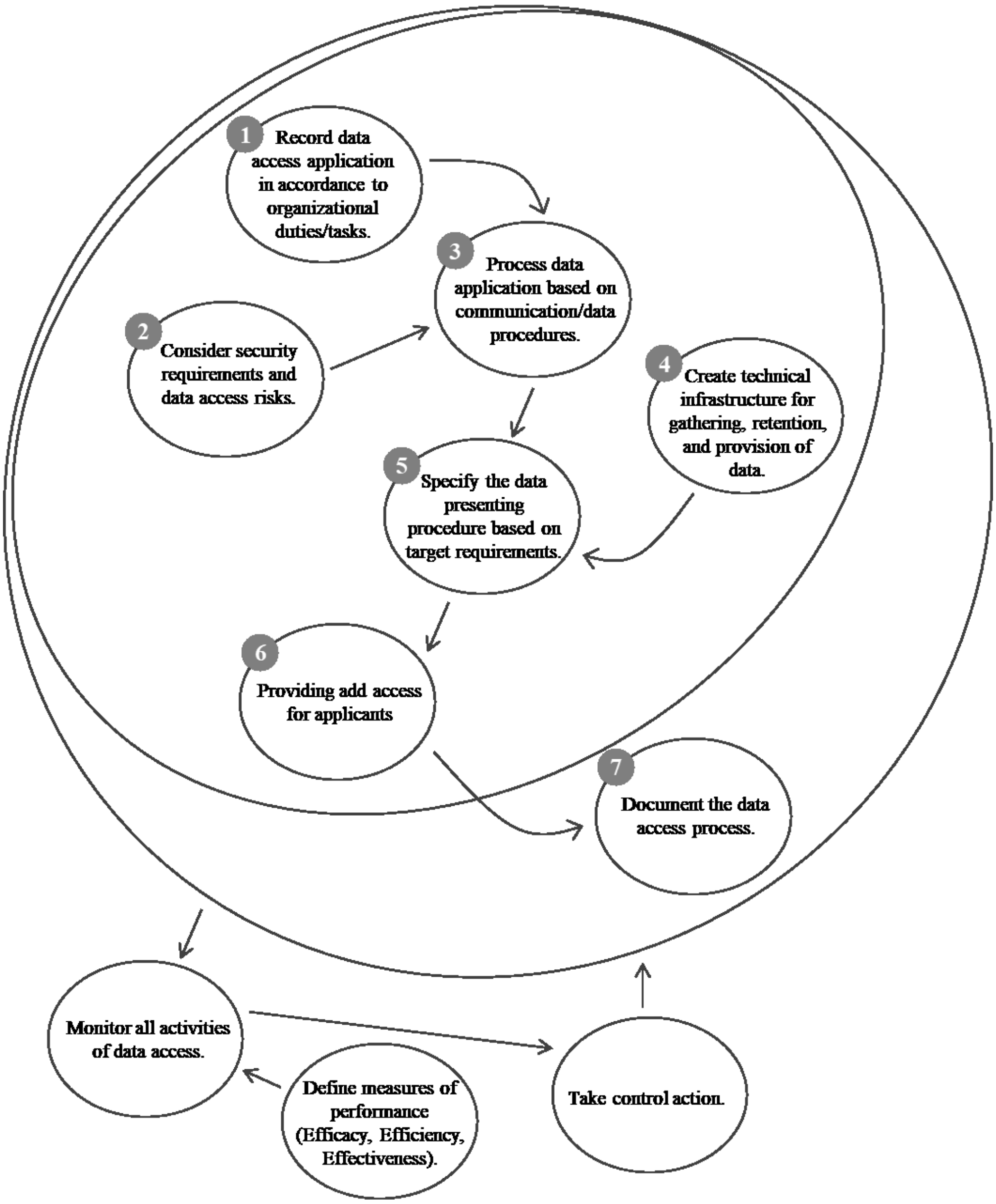

Figure 25. The purposeful activity model for the data access process

Figure 2 presents 7 purposeful activities hinged on the earned knowledge of the problematic situation panned out in two layers. The first layer, incorporating activity numbers 1 to 6, presents issues ranging from data access procedure and application to access permit. The second layer includes the retention procedure and documentation of events. Preconceived activities like monitoring, control, and measuring based on all purposeful system measures are included in this layer.

4.2. Key fields of data governance policy in the data-access domain

Given the earned knowledge of the data access problem via SSM and the resulting conceptual model facilitating the redefinition of the problem and its purposeful activities, the critical fields of data governance policy among the group of data governance programs gain significance.

In this section, by the adopted methodology, the key fields of data governance policy are elaborated, through which key concepts related to data governance correspond to every measure in the conceptual model of SSM. This definition considers performance measures, including the three criteria of efficacy, efficiency, and effectiveness and accordingly, the policy rules set based on the improved performance of data access procedure are given.

Table 3 shows the policy fields for the primary layer in the SSM conceptual model.

Table 12. The fields of data governance policy on data access

	Conceptual model activities	Policy fields
1	Recording data access applications by organizational duties/tasks	1. Redefining the extent of requirement for data based on organizational mission (Dawes, 2010; Janssen et al., 2020; Reichental, 2023) 2. Integrating organizational literature based on marketing nomenclature (Cheng et al., 2017; Shin et al., 2020) 3. Informing and training staff concerning data-oriented interactions (Janssen et al., 2020)
2	Considering security requirements and data access risks	1. Classifying data in terms of confidentiality and sensitivity (Hripcsak et al., 2014; Kim et al., 2014; Reichental, 2023) 2. Determining confidentiality level for extra-organizational and ecosystem-related interactions (Dasgupta et al., 2019)
3	Processing data application based on communication/data procedures.	1. Defining metadata to describe data (Khatri and Brown, 2010; Brous et al., 2016; Abraham et al., 2019) 2. Translating data application in terms of intermediary roles in data governance (Gou, 2022; Reichental, 2023)
4	Creating technical infrastructure for gathering, retention, and provision of data.	1. Preventing access to the online transaction processing system (OLTP) (Mahanti, 2021; Nadal et al., 2022) 2. Focusing on access based on data archive and analytical data centers (OLAP) (Mahanti, 2021; Nadal et al., 2022)
5	Specifying the data presenting procedure based on target requirements.	1. Identifying a safe and efficient channel in terms of data-sharing tasks (Borgman et al., 2016; Janssen et al., 2020) 2. Identifying a safe and efficient format in terms of data-sharing tasks (Eryurek et al., 2021)
6	Providing additional access for applicants	1. Focusing on approved data management environments (Jia and You, 2021) 2. Assigning access to the applicant (Janssen et al., 2020)

As mentioned in the methodology section, the system's performance measures based on the above definitions include the three criteria of efficacy, efficiency, and effectiveness, each of which can contribute to the fabrication of logical procedures based on the policy. In other words, the procedures that determine the details of activities should be investigated in terms of activity-measuring criteria.

5. Conclusion

Having investigated various data access applications in Iran's banking industry and scrutinised volumes of documents on such applications, this study shed light on the current problematic trend through stakeholder interaction. To illustrate the trend and perceive its complex and sensitive situation, SSM was employed so that a transparent and proper image of the problem as well as its root definition and essential components, could be presented. To this end, various trends and procedures were investigated in technical and marketing terms by considering the operational steps of SSM in creating a rich picture of the problematic situation in data access in the data governance domain. In consequence, the SSM model managed to obtain a list of purposeful activities. Upon identifying these activities, the supporting policy corresponding to every set of activities based on the data governance literature, specifically in the data access field, was studied and mapping between activities and basic principles of governance policy was created.

As shown in the Finding section in Table 3, various policy dimensions were divided into 6 classes: data application, risk, processing, infrastructure, route, and access, each of which is entitled to its own literature. This procedure significantly helps achieve an initial document of the data governance policy regarding data access because active fields can be readily segregated in terms of roles, communication and data flow, stakeholders, technical developments, and organizational tasks. This distinction led to classification and helped structure the complex problem of this research and properly identify key fields of data governance policy, hence greater convenience in forming the details of this policy and the corresponding procedures.

This research study achieved an improved situation in the conceptual model out of a problematic situation whose dimensions included multi-stakeholders, multi-perspectives, and complex aspects. With the help of this new, improved situation in the model, we can decide on the data governance policy. Decision-making elements, in this case, were the very key policy fields that had already been separately presented for each activity.

Disclosure statement

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

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Soft Modeling of Engineering Changes in System Dynamics (Case Study: Automobile Industry)

Rashid Faridnia [a*]

[a] *Department of Industrial Mangement, Faculty of Economics, Management and Administrative Sciences,Semnan University, Semnan, iran.*

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ABSTRACT

Effective management of engineering changes in the Automotive industry is an essential ability in new product development, and products evolve in an environment with an iterative nature and increasing changes from the idea stage to the final product and shortening the life cycle of products and also the duration of product Launch from The idea-to-market stage is a severe requirement of a competitive environment. First, the complexity of the product development environment, the challenges of engineering changes and the need to control and governance its effects in a competitive environment in the vehicle development process are described. Then by literature review, an approach to modeling engineering change management using two hard and soft models has been introduced.in our modeling approach, the assumptions of cybernetics and system dynamics approaches have been practiced in building causal loop diagrams that integrated SOFT effects with HARD dimension parameters. Using this approach to develop simulation scenarios, strategic managers have better insight into effective management of engineering changes to find appropriate policies configuration to control its effects in a competitive environment.

Keywords

Product life cycle (PLC), System dynamics, Engineering change governance, Hard and soft modeling.

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****Corresponding author***
Email: rashid.faridnia@semnan.ac.ir

1. Introduction

Engineering change management constitutes a wide-ranging product development basic challenge, introducing considerable uncertainty into the execution of product introduction operations. In the new product introduction, process modifications vary depending on the stage of the project. Variations in the early stages of the project are addressed with design iterations. In contrast, after the product design is augmented, changes are explored using a formal Engineering Change Proceedings. The practices of engineering changes in the automotive industry have complex dimensions, particularly under a joint setting where various autonomous institutions work together for a common target with a complex structure. Since engineering change management is a technical, social system, the existing literature shows significant gaps in examining the complexity of both social and technical subsystems. To ensure a comprehensive approach to engineering change management design, an overview of design elements and their interdependencies is required (Schuh et al., 2018). By enabling planned engineering change management, professionals can improve overall engineering program management and related complexity (Mehr et al., 2021). This paper proposed a digital twin for engineering change to enable continuous quantitative evaluation (hard and soft) and refinement of engineering change governance. According to Shakirov et al., (2021), digital twins may also be practised to analyze systems at the junction of process and organizational fields. In particular, the value of using essential tools such as the design structure matrix (Becerril et al., 2016) from systems engineering principles and basic simulation techniques, such as discrete event simulation for modeling the product introduction, engineering changes and complexity analysis, is emphasized (Li, 2012). Hence Much attention should be given to the diverse origin of uncertainty inherent in engineering practices. Sometimes this cognitive uncertainty is caused by the lack of knowledge about the operation system and its causal relationships (i.e. ambiguity), as well as the apparent uncertainty caused by natural changes in the values of system variables. This paper presents a framework in the form of hard and soft models to explain the interactions between different parameters of the new product introduction process and engineering change management. Hard operational entities (idea, 3D, 2D, etc.) are modeled in systems based on the PLM model (product life cycle). Also, by using the model of a system dynamics simulation model that shows the processes of new product introduction and engineering change framework for a value chain, process (causal) factors are simulated in the soft dimension to understand the interactions of hard parameters and analyze the effects of the change. The finding shows that most relations and interactions between factors and variables significantly affect the launch time of new product development. By using this framework, managers and executives can develop appropriate management policies to configure interactions of engineering processes and engineering changes and investigate uncertainty and complexity in managing their product development projects.

Companies always need changes in their product development system to maintain competition in the market share. But many new product development programs fail because of a lack of attention and effective control of the dynamic nature of essential success factors such as time, cost, quality, scope and change management. The boundary and dimensions of engineering changes are critical factors directly related to other factors. Therefore, to maintain competition and focus on scope, there is a need to manage effective changes in new product introduction programs - a competitive organizational strategic weapon (Rodrigues et al., 2006). To remain competitive, organizations need to develop policies to control and analyze any required changes in their new products that affect the value chain because of specific problems or evolving market conditions and customer requirements. Further, companies need a modeling approach examining and analyzing the scope of engineering change management policies and their effects in the operational dimension (hard) as well as modeling the strategic dimension (soft) using system dynamics models to study complex interrelationships of the influential factors of the product development system in engineering changes (time of product supply to the market, quality challenges, effects in the supply chain, market share and cost). (Bock and Feeney, 2013).

Therefore, the research is presented as follows. How can global manufacturers manage the complexity of Product Hard Parameters Changes and its Soft Effects in different processes and geographical disciplines to respond exactly and quickly to changing and diverse customer demands and suitable Engineering selections to maintain market competition?

2. Theoretical background

2.1. Managing complex changes in the product business

The need to pay attention to the complexity of engineering change, which is a function of sometimes *linear, non-linear, multi-stage and repetitive relationships* in the components of the business organization, product, process, design team and environment in order to obtain an overview of the scale and connections It is necessary through a comprehensive approach. The reason for this is the vast potential of an engineering change. A simple technical change may have non-technical effects on various attributes such as process, time, organization, and product brand. Reflecting on the potential impact of engineering change allows for consideration of the complexity dimensions of change (hard and soft) that will be explained later. A summary of studies conducted by researchers in different engineering change management dimensions is presented Table 1.

Table 13. Complex methods and Techniques of engineering change management

ECM practices and Tools	Explanation	Source
Development of a transparent engineering change management process and procedure	A transparent engineering change management operations should include: (1) bringing up an engineering change quest, (2) identifying possible resolutions and clarification to the EC request, (3) evaluating the effects of feasible solutions, (4) selecting and validate a resolution, (5) implement the EC solution, and (6) review the feedbacks.	Jarratt et al., (2005); Wickel et al. (2015)
Determining the coordinator of engineering change activities	A person responsible for following up and coordinating the engineering change governance should be determined.	Huang and Mak (1999)
Creating a multi-disciplinary team to work on engineering change	different teams are needed, representatives from different fields; for example, design, engineering, production, purchasing and planning	Huang and Mak (1999); Sjögren et al. (2018)
Production participation in the early stages of design and engineering	The manufacturing organization are needed to be involved in the early stages of the design and engineering practices to determine future production non-conformities and implement the essential modifications at an early phase.	Huang and Mak (1999); Jarratt et al. (2011)
Participation of suppliers in the process of evaluation and implementation of engineering change and inter-organizational engineering change management operations	Suppliers affected by an engineering change should participate in the early stages of engineering change assessment and implementation to detect and evaluate all engineering change releases early. In addition, a common inter-organizational engineering change management standard is needed to ensure proper and timely evaluation of engineering change and implementation operations.	Rouibah, Caskey (2003); Wasmer et al., (2011)
Separate meetings to work on engineering change	Multi-disciplinary teams should have specific engineering change meetings. This ensures that all information related to engineering changes is considered and promptly available to all functions involved.	Huang and Mak (1999); Sjögren et al. (2018)
Centralized access and Documentation to the status and logs of engineering changes records	Engineering change information must be suitably documented and centrally stored to ensure that it is available to all departments timely. Information should be presented to allow users to track engineering change logs.	Morris et al. (2016); Sivanathan et al., (2017)
Making decisions about engineering changes at the lowest possible management level	Engineering change decisions are needed at the lowest possible management level to save resources used for engineering change implementation. Different approval levels can be used depending on the engineering change's cost or risk level.	Stevens and Wright (1991)
Computer-based techniques to support the complexity of engineering change management		
Special IT systems for engineering change management	Special IT systems developed by professionals support change engineering documentation flow, obtain and store change engineering knowledge, assist change engineering evaluation, and enable collaboration.	Chen et al. (2015); Sivanathan et al., (2017)
Configuration management systems	Configuration management systems institute and maintain related information and product integrity to effectively control product changes. These systems assist in evaluating	Jarratt et al., (2005); Whyte et al., (2016)

	engineering change and storing, exploring, and updating information related to engineering change.	
Product Data Management / Product Lifecycle Management systems.	PDM and PLM systems help to efficiently manage and distribute data and coordinate product creation processes among stakeholders. These systems can be used to effectively assistance of the engineering change planning, approval and implementation steps.	Do (2015); Wu et al. (2014)
Building information modeling	BIM is a multi-disciplinary and collaborative environment that includes a digital representation of a product's physical and functional specifications. BIM reduces the number of emergency engineering changes and assists in evaluating engineering change releases.	Francom and El Asmar (2015); Saoud et al. (2017); Matthews et al. (2018)
Tools for reducing and promoting change		
QFD	QFD technique is used to convert customer requirements into product engineering specifications. QFD helps capture customer requirements and needs at an early phase, thus reducing upcoming customer changes.	Huang and Mak (1999)
Analysis of failure modes and effects	The FMEA technique figure and reduce the potential problems of a product. If done early in the states, FMEA reduces the number of internal engineering modifications due to errors and changes in the early design stages.	Braaksma et al. (2013)
Design tools		
Design for Manufacture and Assembly (DFMA)	DFMA is a Technique used to design products for easy and economical production. DFMA is a common tool to integrate fabrication and assembly requirements into the early design steps and prevents emergency changes in production and assembly processes.	Das and Kanchanapiboon (2011); Jarratt et al. (2011)
Design for Flexibility (DfC)	DfC aims to design systems and products where upcoming engineering changes could be quickly implemented or avoided. Changeability could be attained through the principles of simplicity, independence and modularity.	Fricke and Schulz (2005); Ross et al. (2008)
Design Freeze	Design freeze is the final gate in the design activity where design evolution stops and the records are delivered to production. This technique limits the counts of engineering changes that can occur	Dieter (2000); Eger et al. (2005); Gosling et al (2013)
Impact assessment and change diffusion tools		
Change prediction methods (CPM), design structure matrices (DSM)	CPM and DSM are techniques that apply a matrix to represent the dependencies between product components and a method to predict and analyze the effects of releasing changes.	Hamraz et al. (2015); Zhao et al. (2010)
System Dynamics	System Dynamics is a modeling framework that can be applied to analyze engineering change causes and dynamic behavior of projects by feedback loops. This methodology gives insight to managers about how engineering change impacts project performance.	Ansari (2019); Love et al. (2002)

Also, the literature includes a wide range of other studies in the field of managing engineering change: the study of design and Engineering modifications and changes in the form of change stages, change parameterization, change workflow in the form of web systems, the effect of change in terms of possible factors, and the mathematical model of change implementation time, to minimize the effect of change and look at the change in the form of a discrete entity and modeling it by the discrete event method.

In this study, based on field studies and experiences in the automotive industry and referring to industry experts, as well as the following reasons, we chose the system dynamics for dynamic change methodology:

- The number of engineering changes is large, and the target product (car) structure is complex.
- Discrete event modeling and seeing change as a discrete entity leads to big and massive data for tracking each entity's flow.

2.2. Product introduction system and engineering change governance

The above studies emphasize the necessity of using systematic methods, product development and different techniques to systematically manage product development and engineering changes.

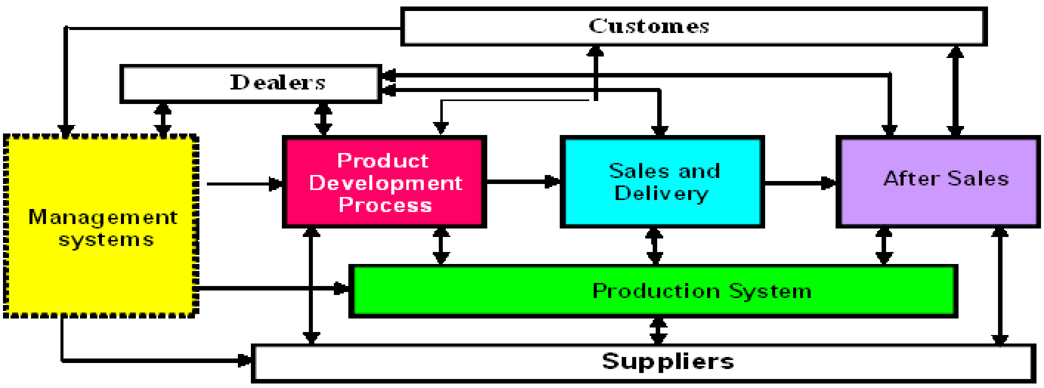

Figure 26. The comprehensive system of manufacturing companies in the automotive industry (Ford)

One of the critical systems in Figure 1 is the product development process of the automobile industry; this system, using the V methodology (Hartman and Kenley, 2015) of systems engineering (Figure 3) and the Stage-Gate system (Cooper, 1976). The model of physical requirements in a systematic way is mapped into functional areas and from functional areas to the design parameters and from the design parameters to the physical domain of the product (Fei et al., 2021).

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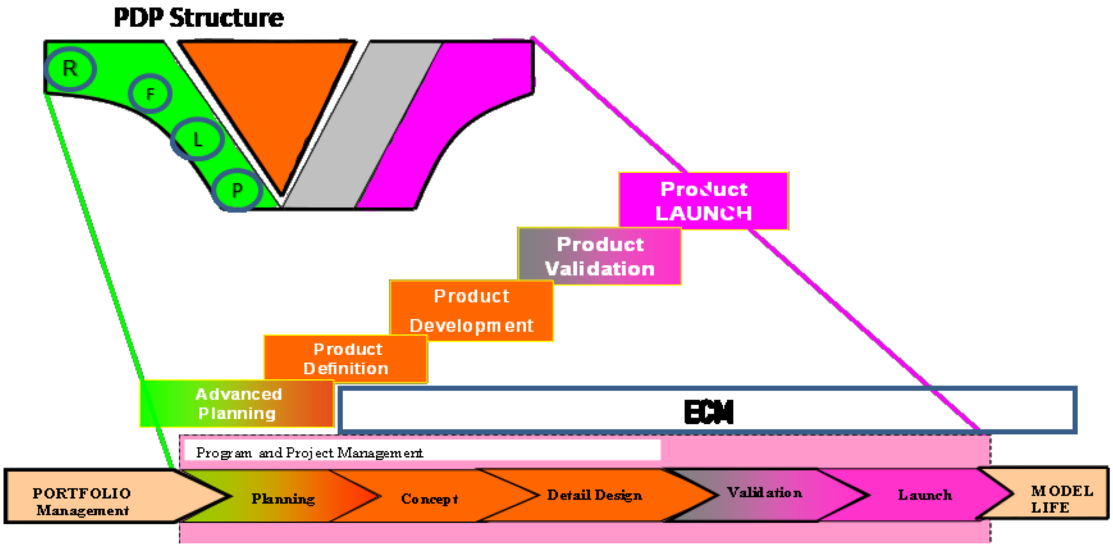

Figure 27. Model-based systems engineering in the vehicle development process

The input of this system is ideas or issues of engineering changes with an internal or internal origin: research and development, technical or external issues: market, competition, laws, regulations, norms. As a result, product improvement or development processes are initiated to improve (change requests) with reports on system problems or suggestions and ultimately make changes to the specification, including when they are produced. Change operation as a part of system development prioritizes change requests, and proposed change orders are attention based on the impact criteria on the productivity and profitability of the engineering organization instead of paying attention to the extent to which the orders make the change request.

A proposed change order may fully respond to the change request but have a negative impact on the organization's productivity and profitability. In contrast, another change order may partially respond to the request and improve the organization's productivity and profitability. In contrast to common terminology, change requests describe the situations that lead to the requests. For example, when systems behave in undesirable ways, instead of suggesting system modifications that the requesters believe will eliminate the undesirable behaviors, they describe the undesirable behaviors and the circumstances in which they occurred. Change requests enable engineers to determine the importance and priority of handling change requests and consider more and possibly better change orders for the same requests. Change requests that only suggest system changes are changed orders that engineers are forced to guess the underlying situation. When wrong guesses may reject legitimate and acceptable requests or propose solutions that do not solve the real problem, engineering change processes require considering requested changes and the impact of potential change orders on the rest of the system and the engineering organization producing it. Change issues must usually be prioritized due to system development and production resource constraints and analyzed for the possibility of cascading changes. Another issue is the iterative and repetitive nature of new product introduction and development processes, which assumes changes are made during new product development processes. However, changes after the completion of the new product introduction program and the launch of the new product to the market must be directed through a formal process called engineering change management. In the ECM, any changes in the product record and data after the finalization of the design must be communicated and transferred to all the related stakeholders. The purpose of EC is to improve the product by different measures, including correcting errors related to design, upgrading technology, or improving product performance. Due to the increasing effects of the engineering change management process on the product launch, lead time and cost, its importance in competitive environments and respond to new and changing market opportunities is very high. In many situations where the manufacturer is involved in engineering change management due to customer-supplier relationships, the complexity of the engineering change management process increases significantly. So it will be essential to create a set of PLM client-server procedures and systems that controls the interaction and flow of information between the different stakeholders (Tavcar and Duhovnik, 2006). When the complexity of the engineering change management process increases due to the involvement of multiple organizations, it becomes necessary to study the effects of some engineering change management procedures and policies on the entire supply chain and Original Equipment Manufacturers (OEM) before the actual implementation of the course of action and policies (Mutingi et al., 2015). In such environments, the engineering change management process simulation provides an understanding of the critical factors affecting the engineering change management operations and assists in identifying the process's weak components. Also, by simulating the engineering change management process, the effects of policy changes can be seen without actually implementing them.

2.3. Hard and soft modeling of engineering changes

Model-based methodology and approaches are a digital framework for specifying systems and products that integrates engineering concepts into computer languages and enables engineering-friendly computational assistance for developing system characteristics and definitions. They are famous for providing significant performance improvements in system characteristics and definition than document-based methods. Using modeling languages and approaches, engineers create system models that express engineering cognitions, decisions and choices in digital ways. One of the essential capabilities of model-based methodologies for engineering changes is to facilitate the "propagation of changes" (Giffin, 2007). Management of engineering changes requires modeling beyond the relevant system itself. Changes must be separated from the modeling specifications (hard model) so that the same changes can be made in several specifications. For example, applied to common aspects of different types. In addition, change models enable the specification developers and other practitioners easily understand and figure out how the new specification and parameters have changed and determine its impact and effects on their tasks (Figure 3). Also, the effects of changes and cause and effect loops, and change dynamics over time require soft modeling (Grzegorzewski et al., 2019).

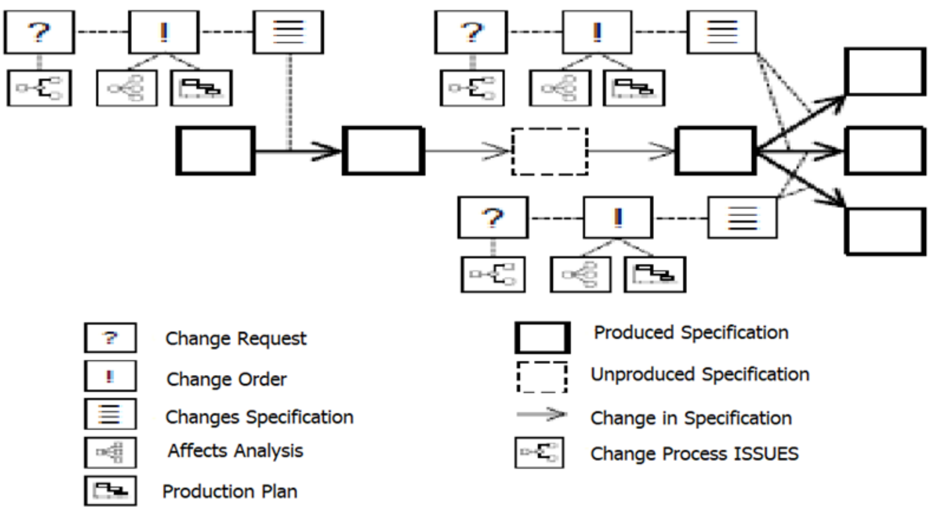

Figure 28. Engineering change modeling

More modeling techniques could be used to model any system, but a number of them are more suitable for modeling specific systems or certain aspects of systems. For example, Integrated DEFinition (IDEF0) is a family of modeling languages that starts with and is more suitable for systems and software engineering work (Fei et al., 2011b). While the functionality of the IDEF family has expanded from the most functional modeling language in IDEF0 to the simulation modeling languages in IDEF3 and above, they are more suited to modeling functional and data relationships in systems. Analyzing feedback mechanisms with proportional and rate functions in the system dynamics model is unique (Reddi and Moon, 2013). Engineering changes may occur at different stages during the multi-generational product life cycle, from the requirements in the design stage to the production product, and various parameters are involved in the cause-and-effect loops. For a deeper understanding, find the dimensions of change and feedback mechanisms; this section examines the dynamic (Soft) modeling framework of change management.

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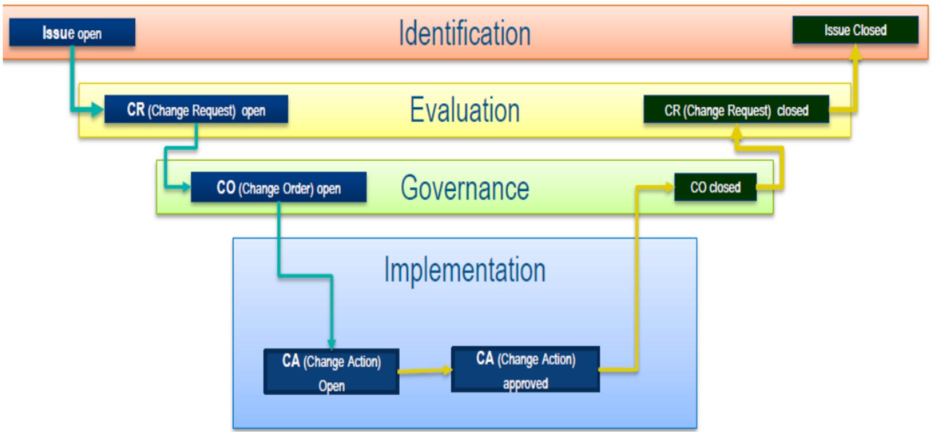

Figure 29. The levels of engineering changes and the need for soft modeling of the effects

As mentioned earlier, engineering change management consists of four levels (Figure 4). One of the steps is to evaluate and estimate the impact of engineering changes of any solution for engineering change requests, considering the risk of its implementation, for example, the impact of changes on design and production plans.

When a stakeholder makes an engineering change at the requirement, function, or component level, release risk is calculated to the extent of the risk of changes in tasks. Two cases are distinguished; engineering changes can start a new task or cause rework in an existing task. To study the dynamics of this issue, the need to develop soft models of engineering changes to analyze the dynamics of the project and the impact of changes on others.

3. Methodology

System Dynamics is a modeling approach and methodology used to model, study and manage complex systems. System Dynamics identifies system variables and defines their links (relationships) to create system structure. A model grounded and based on system structure is simulated to identify the system's leverage points. The relevant model includes accumulation, flows, time delays, variables and feedback loops, representing a system or a part of a system. Here, "system" refers to interdependent or independent components or entities that work together for a common purpose. A system component can be considered a system itself; its dynamics are grounded on causal loop diagrams (CLD). Causal loops diagrams (systems thinking diagrams) are "mental maps" of the system or problem involved. An SD model consists of system variables connected through CLD. These diagrams may or may not be complete or accurate because they are visual representations of the system by Relevant stakeholders are understood. A sink with input and output can represent a build-up in an SD model. The sink level fluctuates depending on the flows passes through the inlet and outlet valves, while the accumulation level is also defined by the inlet and outlet rates quantities. Accumulation accumulates and stores streams at a quantity equal to the difference between the input and output rates. Inventory quantities determine the status or state of the system at any point in time; flows are defined by "auxiliary variables", which are functions and accumulation functions, and the logic of the process as a whole in these variables. Rectangles figure out accumulations or state variables, while flows are shown by into and out arrows of the accumulation, indicating inflow and outflow. The valves on the arrows control the magnitude of flows into and out of stacks or state variables. The source is displayed with a cloud icon. The source has an arrow going out, while the sink has an arrow going into the cloud; together, these define the range of the model.

3.1. Methodology of system dynamics modeling of new product introduction processes and engineering change governance

Dynamic and cybernetic system for modeling engineering change governance in a new product introduction program by separating and classifying the type of collaboration between manufacturers and operations characteristics such as resources, resource combination, phase overlap, processing quality, processing rate, allocation priority, sourcing, change propagation and grouping of engineering changes and evaluating its impacts on OEM performance is studied.

3.1.1. Causal loop problem and diagram

Using system dynamics with causal loop diagrams, an organisation's new product introduction and engineering change management are modeled to identify the relationship between the parameters of the new product introduction process and engineering change operations. The causal diagram above shows the system variables in the processes; it identifies new product introduction and engineering change management and shows the effect and chain relationships. Arrows indicate links and relationships between system variables, and the type of relationship between variables is indicated with a sign at the head of the arrow. It is assumed that, at best, a company cope with changes in its market share by making changes to its products to gain or maintain its market share depending on the direction of the change. Any change initiated by an organization to modify a product is generally considered an engineering change. From the CLD (Figure 7), six loops can be identified:

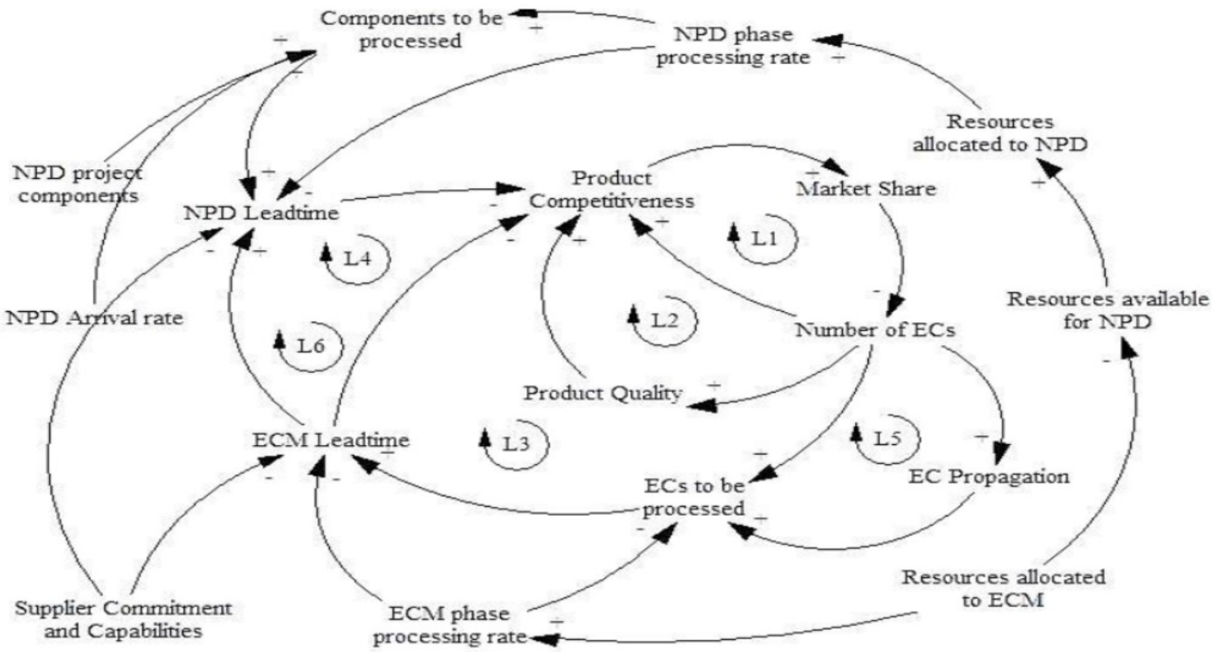

Figure 30. New product introduction and engineering change governance Causal loops and process parameters

- L1: Market Share—Number of ECs—Product Competitiveness
- L2: Market Share—Number of ECs— Product Quality—Product competitiveness- Market Share
- L4: Market Share-- Number of ECs— ECs to be processed—ECM Lead time—NPD Lead time —Product competitiveness- Market Share
- L5: L4: Market Share-- Number of ECs— EC propagation-- ECs to be processed—ECM Lead time——Product competitiveness- Market Share
- L6: Market Share-- Number of ECs— EC propagation--ECs to be processed—ECM Lead time—— NPD Lead time —Product competitiveness- Market Share

At the L1 loop, a decrease in market share increases the number of engineering changes, increasing the product's competitiveness and higher product competition increases sales and market share. The second loop (L2) includes the market share of the engineering change link and then the impact of the number of engineering changes on the quality of the product, so the number of engineering changes increases the quality of the product, which in turn improves the competitiveness of the product in the market and understandably increases the market share of the product. For the L3 loop, any increase in engineering changes increases the number of engineering changes to be processed, increasing the engineering change management delivery time. Any increase in engineering change management time increases response time to any market opportunity and thus reduces product competitiveness. For the L4 loop, any proposed engineering changes before the product launch increases the lead time. Also, a rise in the response time reduces the product's competitiveness level. For the L5 loop, a rise in the number of engineering changes escalates the number of engineering changes to be processed, which again lengthens the engineering change management delivery time. Any rise in engineering change management lead time increases response time, making the product less competitive and maybe a fall or loss in the market share. In the cases shown in loop L6, if engineering changes and releases occur before the product is released, this will expand the lead time to develop the new product. Any rise in the delivery time of new product development delays the product's market launch, which reduces the product's competitive ability (due to customer trust lost and other product sales) and then the product's market share. While L1, L2 are negative loops, L3, L4, L5, and L6 are positive loops. Most likely, the result will be the combined effect of all these loops.

3.1.2. Organizational models based on system dynamics explain how manufacturers interact with the company in product development.

Organizational patterns have been proposed because OEMs interact with their suppliers at more or less fixed stages in the new product introduction process. Communication with suppliers may involve the physical transfer of materials or just the sharing of information. These suggested patterns are measured grounded and based on the new product introduction process and their participation in the company's new product development phase and stages (Figure 8).

3.1.3. The dynamic model of engineering changes

The following template represents an original equipment manufacturer or an organization in general. The template forms the process framework of new product introduction and engineering change governance of the organization and provides the possibility of interacting with suppliers at the right time. The new product introduction and development process includes five main phases and stages: concept generation, detailed design, prototyping and testing, production ramp-up, and product assembly and testing. The engineering change governance process includes several steps, such as proposing an engineering change request, approving an engineering change, planning and implementing an engineering change, and documenting an engineering change The main factors that affect the workflow of NPD stages and engineering change operations governance are point out and determined in the model as variables that can be changed to modify the model's behavior accordingly. A new product development program is assumed to progress at a specific rate (e.g. one or more projects per year). Each new product introduction program can be broken down into smaller, independent parts called "components". As the design progress, the number of new product development components is determined, and the components are transferred to the relevant organizations for processing. These organizations include companies and suppliers participating in the new product introduction process from the concept phase. Organizations design and test product design in three stages: concept, detailed design, and prototyping. Once the product prototype is tested, production ramp-up begins with the goal of producing the product at a value determined by sales forecast estimates.

Feedback loops assume a specific percentage of error in the process at each phase and stage of new product development. For example, during a concept processing task, components with conceptual errors are collected separately and sent to the loop to rework the concepts, introducing a delay controlled by the error detection rate quantities. Errors in later stages of NPD are also assumed to propagate to earlier stages of the process. For example, a specific fraction of discovered design errors are sent to concept processing, assuming error propagation that has led to the re-evaluation of concepts.

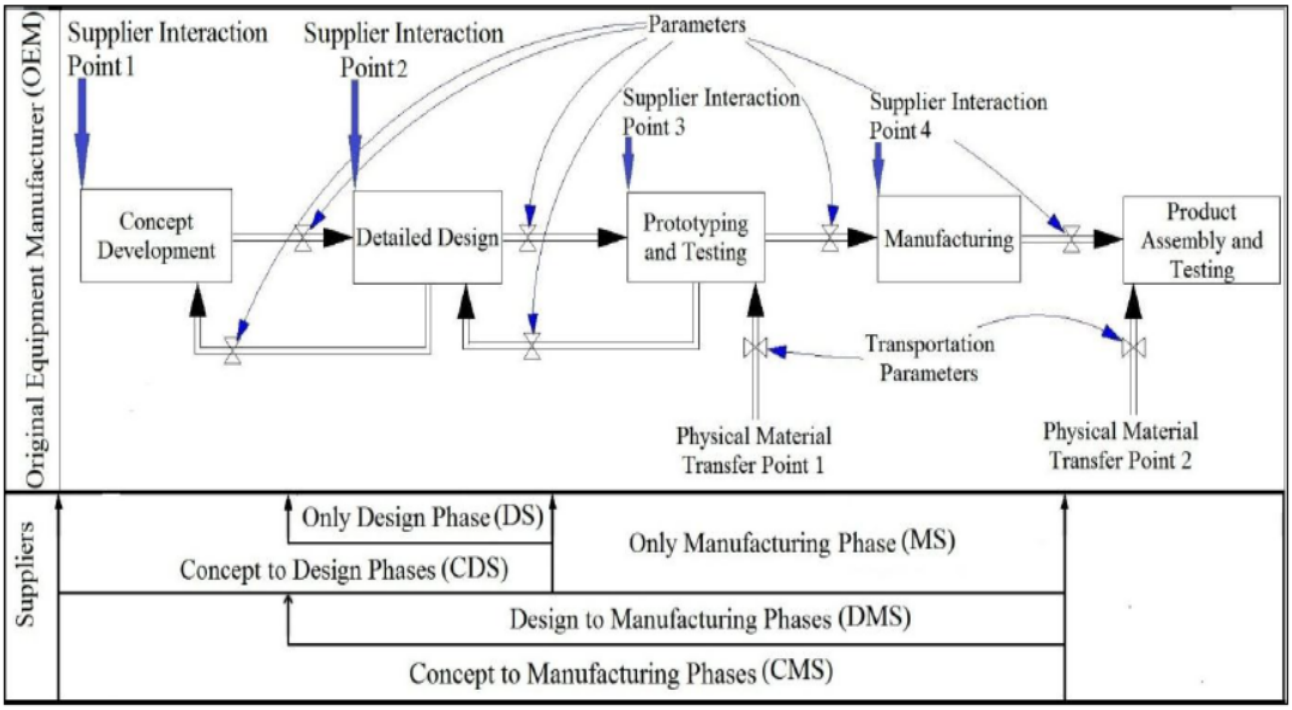

Figure 31. Schematic form of organizational patterns of interaction with the manufacturer and its role with the OEM

Components (detailed designs/design concepts in the form of production drawings/selected technologies) are sent from the company to suppliers for prototyping as detailed component designs are completed. Prototype components (manufactured prototypes) are returned to the company as manufactured by suppliers. After the successful assembly and testing of the product prototype, the parts are transferred to suppliers for increased production. Parts (ready for product assembly) flow from the suppliers into the company for product assembly and post-production testing. Changes discovered during and after prototype assembly are considered engineering changes and are processed using the standard engineering change management process. When discovered, components affected by change engineering are transferred to engineering change management, where the engineering change is analyzed, planned, implemented, and documented. The diffusion of changes is included in the text with the help of a diffusion index with a value higher than 1 and determines the diffusion of engineering change among components. It is also assumed that suppliers and customers introduce engineering changes. Components affected by change engineering flow from engineering change management, where the engineering change is planned and analyzed, back to suppliers or the company for implementation to the manufacturing stage for rework (Reddi, 2011).

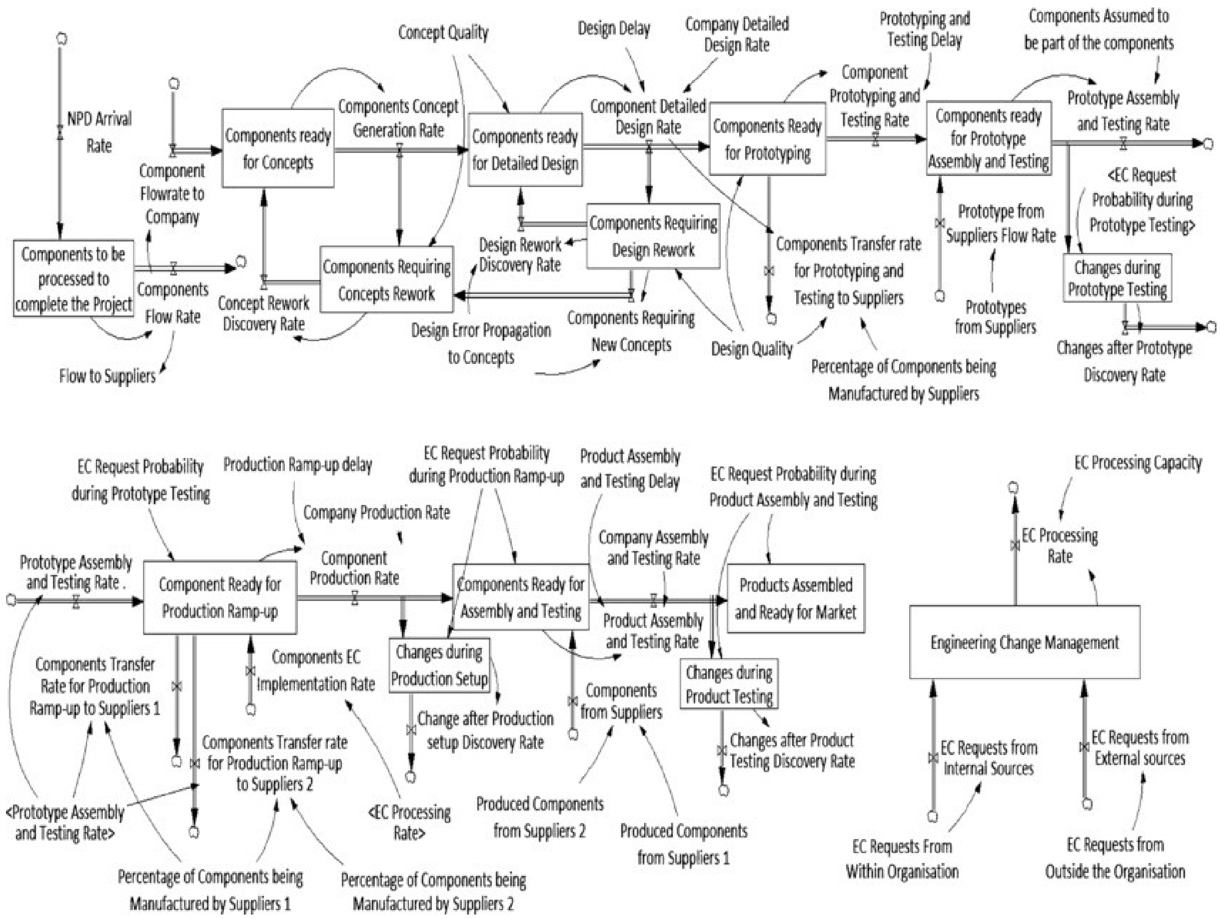

Figure 32. OEM model template

3.1.4. Models for distinguishing supplier interaction in new product introduction and engineering change governance

The OEM model described above is drawn accordingly to represent the suppliers involved in the various stages of product development. For simplicity, suppliers are assumed to be involved in various stages, from concept development to product testing. This model shows cases where the company defines the specifications and the supplier designs and manufactures the parts. When the number of components that are part of the new product development project and each supplier manage it, they flow to the supplier. The supplier develops the concepts, designs the product and produces the prototype according to the guidelines set by the company. The components are returned to the company in the form of prototypes for assembly and testing of the prototype. After assembly and successful testing of the prototype, the parts are sent to the supplier for production. The components produced for product assembly and testing flow to the company during production.

Engineering change management has requests from internal and external sources. External sources include the company and downstream suppliers, if any. As in the Initial model, the components affected by the engineering change are multiplied by a diffusion index to address the engineering change diffusion. Below are summarized four models of the system dynamics for separating the cause and effect loops of constructive interaction with the company from the above model:

1- Involved in design and construction 2- Only in construction 3- Only in conceptual and design phase 4- Only in the design phase

The first state represents the supplier who designs the part according to the specifications provided by the company. The manufacturing company completes the part concept, decides on specifications such as technologies, performance requirements, etc., and sends the part specifications to the supplier. Parts are transferred from the company to this type of supplier after the concept production stage. The supplier designs the parts according to the specifications received from the company. The part is prototyped and transferred to the company for assembling and testing the prototype. After successful product prototype testing, parts are sent to the supplier along with sales forecast information to increase production. The supplier produces the parts and sends the product to the company for assembly and testing. This supplier's engineering change management process handles engineering change requests from external and internal sources. Each engineering change has a release index, which uses a value greater than 1 to indicate the components affected by the release of the change. The second stage is a supplier only involved in the production phase. This model represents a supplier not engaged in the manufacturing or, at least, in the company's product design. As the company completes the detailed design of the parts, a portion of the parts produced by the suppliers are sent to the suppliers who produce the prototype parts and return them to the company. Once the assembly of the product prototype has been tested and approved for scale-up production, the components flow to the supplier who manufactures them and is shipped to the company for product assembly and testing. In this case, engineering change management handles requests after production setup. It mainly analyzes the engineering change to decide if the part needs to be reworked or if it should be made from scrap. This type of supplier has an engineering change governance process, but it is assumed only to plan the engineering change implementation process. Third pattern; full-service Supplier involved in concept and design: This pattern represents design partners who are only involved in the stages of the conceptual and detailed design of the product life cycle. After the components of new product development are specified, the components flow from the company to the supplier. Parts are returned to the company as the designed parts. This supplier does not have a separate engineering change governance process but participates in the company's engineering change management process. The fourth pattern of a supplier that only participates in the detailed design shows that the company chooses the appropriate technology and characteristics of the desired components for design and manufacture. After selecting the appropriate technologies, the company may outsource the design work to an engineering partner that specializes in those technologies. The concepts of the parts are transferred to the supplier, who designs the parts and sends the designs to the company after completion. The feedback loop mechanism provided in the template indicates errors in the design process. This type of supplier does not have a separate engineering change management but participates in the company's engineering change governance process.

4. Conclusion

In any case, engineering changes are inevitable. Also, the need to pay attention to the repetition and the source of repetition of change is necessary. The origin of the identified changes or problems and errors results from the activity results (data and design information), new requirements' introduction, or the design scope's enlargement.

The need to pay attention to the complexity of engineering change, which is a function of the product, process, design team and environment, can be explained in the frameworks of hard models (algebraic relations) and soft models of cause and effect (differential relations) and this issue in the soft model in the variables under the title of the number of changes, the number of repetitions, the uncertainty of the solutions, the effects of the learning curve, the completeness of the solution, the uncertainty of the environment and other topics are analyzed, and the balancing and reinforcing circles are identified and then the necessary policy can be made for the problem and developed and evaluated the dynamic hypothesis of engineering change.

This study presented the soft modeling paradigm of the engineering change management process throughout the new product introduction environment to study the dynamics and effects of policy on supply chain operations. The important suppliers in the engineering change management process can be identified by modelling the engineering change management and analyzing the results. Consequently, appropriate precautions can be taken to avoid bottlenecks in the process. The simulation study assumes that each organization has similar initial stages in the new product introduction and engineering change governance processes. At the same time, their details may differ in the policies of processing tasks of engineering change and new product development. Organizations that are part of the supply chain interact with each other at specific points in the new product introduction process. Suppliers interacting with the company are categorized and grouped based on their participation in the new product development process. It is also assumed that the basic structure of new product introduction and engineering change governance processes is the same in a group of suppliers. At the same time, their level of cooperation with the company may differ. In order to use commonalities between new product introduction processes and engineering change governance of supply chain organizations, a set of company and supplier standard patterns were introduced and presented for modeling new product introduction processes and engineering change governance throughout the supply chain.

According to the above models, the comprehensive model could be developed to analyse new product introduction and engineering changes and their effect on the value chain and the market. The parameters of the model and the relationships of differential equations applied in the model, the policies of change and structure, the configuration of the value chain, optimization of parameters, outsourcing and its effect on reducing lead times, ranking and tiering of manufacturers and other challenges can scenarioized and simulate.

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

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Using System Dynamics to Model the Interaction Among the Factors of Job Satisfaction, Productivity, and Quality of Service in the Health Industry

Yahia Zare Mehrjerdi[a]* Tahereh Aliheidari[a]

[a] *Department of Industrial Engineering, Faculty of Engineering, Yazd University, Yazd, Iran.*

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ABSTRACT

Management in health organizations is always interested to know whether their employees are satisfied with the type of job that they are doing. The trend of job satisfaction is of great concern to all employers all around the industries. The health industry is one of those industries where job satisfaction plays a vital role in its performance and providing quality service to patients. Knowing that many studies have been done about job satisfaction in the health industry, only a few are paying attention to the dynamic impact of factors on each other, considering feedback loops for real modeling of the problem. This paper proposes a multi-stage model for evaluating job satisfaction by system dynamics in a big hospital in Iran. Firstly, key influenced factors of job satisfaction are listed based on the Job Descriptive Index. In the second stage, after designing influence diagramming, three scenarios are developed for examining the impacts of two crucial financial and nonfinancial rewards factors. Finally, we analyzed the result of the running flow diagram of each scenario. The results show that applying both financial and nonfinancial rewards simultaneously can increase job satisfaction and the organisation's income via applying one of them.

Keywords

System dynamics, Job Satisfaction, Healthcare, Quality of service.

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****Corresponding author***
Email: yzare@yazd.ac.ir

1. Introduction

There are a few types of Job Satisfaction (JS) models focusing on the thoughts and viewpoints of people about their jobs. Some researchers have concluded that what makes a job satisfying or dissatisfying does not depend only upon the nature of the job but on the expectations that individuals have of what their job should provide. One of the most used definitions of job satisfaction is “an emotional state resulting from appraising one’s job (Locke,1969)”. Researchers have provided different definitions for JS. Some of these definitions are given below to pay attention to their differences. Herzberg et al., (1959) define JS as “a function of satisfaction with the various elements of the job”, while Kuhlen (1963) defines JS as the “individual matching of personal needs to the perceived potential of the occupation for satisfying those needs”. Gruneberg (1976) defines that as “all the feelings that an individual has about his job “. Stone et al., (2020) looks into job satisfaction as “the degree to which employees have positive attitudes towards their jobs”. According to Locke (1969), “job satisfaction is a pleasurable or positive emotional state resulting from the appraisal of one’s job or job experiences”. Research has shown that job satisfaction in the fast food industry is very low due to its fast-working environment, hard-working condition, and the part-timing nature with which employees have to deal. A part-time person working at some of the fast food restaurants in the USA has to go back and forth three times a day to work about 6 hours a day while taking low pay home also. These people need cars to go to work three times a day, which is impractical and unmanageable for most employees. These are reasons why the employee turnover rate in the fast food industry is at a record high due to job dissatisfaction. These led us to notice why absenteeism is high and employees are stressed almost all the time for their job and family as they are working. Ivancevich (2007) pointed to this reality that “there should be a feeling of the right job” for every employee to stay productive. This is true that employees spend about one-third of their day at work, so it is better that employers look for the right employee that fits the job and makes the employee happy at the same time for doing job that he likes; good pay gets. Mengistu Bali (2015) studied the factors associated with job satisfaction among healthcare workers at West Shoa zone public hospitals in Ethiopia. Researchers noticed that the correlation between the different aspects of job satisfaction was significant. They found that the respondents' age, profession, education level, future intention, service year and participation in decision-making was significantly associated with job satisfaction. Looking into health center job satisfaction, researcher Krogstad et al., (2006) studied Job satisfaction among the doctors and nurses in a Norwegian hospital. Researchers found that "the only domain of work significant in predicting high job satisfaction for all groups was the positive evaluation of local leadership". The analysis suggested that professional development was most important for doctors at that health center.

Mental health professionals working in the Italian National Health Service were not satisfied with their jobs. The findings revealed that job satisfaction increased with increasing age. No difference was found between the levels of job satisfaction among different professional roles, as Gigantesco et al., (2003) reported. Job satisfaction of physicians and general practitioners at a health center in Lithuania was studied by Buciuniene et al., (2005). However, doctors who had a longer service were found to be more satisfied with their jobs.

Employees are an organisation's primary asset, so their job satisfaction levels are always of great concern to their employers. How employees have treated at the workplace influences their performances and productivity and impacts the clients and customers. Library's Patron satisfaction trend over time is a highly regarded measure for university and public librarians to know how people think about their performance. Zare Mehrjerdi et al.,(2020) have researched the analysis of health-related factors with their impacts on economic growth. System dynamics was used to model the interactions among key factors to determine the trend as time passes. Through the literature review, authors found that researchers Gupta and Gupta (1990), Mutuc (1994) and Holmström and Elf (2004) have completed research on job satisfaction using a system dynamics approach. Faregh and Zare Mehrjardi (2014) identified effective factors for promoting the therapeutic tourism industry using a system dynamics approach. Faezipour and Ferreira (2013) studied a system dynamics perspective of patient satisfaction in healthcare. Najafi et al., (2019) explored the role of lean thinking in the sustainability of the healthcare supply chain with a system dynamics approach. Zare Mehrjardi (2013) researched weight-related health problems using a system dynamics approach. In 2012, this author studied healthcare costs using a system dynamics approach. The main purpose of this research is "to study the impacts of job satisfaction on the patient's satisfaction and quality of service level provided in health industry taking feedback loops into the modeling of the problem". Such studies are rare in the literature, as the authors show in the literature section of the article.

The rest of this article is organized as below. Section 2 describes the background of the research under study. The literature review is the topic of section 3. Problem description and research contribution is the topic of section 4. Research methodology and model development steps are the topics of section 5. The dynamic hypothesis is discussed in section 7, while stock

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and flow diagramming are described in section 7. Scenario analysis is the topic of section 8. Converting a casual loop to a stock-flow diagram and running it by VENSIM is the topic of section 9. Analysis of the result and authors' conclusion is presented in section 10.

2. Research background

The main elements of this research are discussed in the sections below under the subtitles of Job satisfaction, health industry and system dynamics.

2.1. Job satisfaction

What makes a job satisfying or dissatisfying does not depend only upon the nature of the job but on the expectations that individuals have of what their job should provide. As researcher Locke (1969) mentioned, one of the most used definitions of job satisfaction is an emotional state resulting from appraising one's job. However, the individual matching of personal needs to the perceived potential of the occupation for satisfying those needs is another definition of job satisfaction. Guidelines for job satisfaction can be stated, paying attention to key factors such as communication, culture, security, leadership, opportunities, career development, working conditions, employee personality, pay and benefits, rewards and recognitions.

2.2. Health industry

Pay attention to the workers job satisfaction who do the main tasks in health centers daily. Employees' satisfaction directly impacts workers' productivity and hence the health industry's bottom line. Since the health of a society is at the hands of its health workers paying attention to their job satisfaction is a must. AlaviRad et al., (2015) stated that economic growth contributes to better health, leading to a better economy. So, we can claim that workers' physical and mental health increases the efficiency and quality of work at workstations.

Researchers have employed different approaches to studying job satisfaction at health centers. One type of research on this subject was related to the level of satisfaction by considering working conditions, salary and benefits, and supervision. The second group of researchers looked into the personal demographic or workplace characteristics (i.e., age, gender, practice setting, and position) to determine the differences in the overall level of job satisfaction. Other researchers examine employees' qualifications, skills, commitment, and intention to leave the system. Taking system dynamics as a modeling tool to integrate many key factors is rare in the literature. Zare Mehrjerdi and Aliheidari (2014) have employed system dynamics and artificial neural networks to evaluate job satisfaction in the service industry. However, using system dynamics as an approach for this topic is very suitable because the interactions of several factors affecting job satisfaction are always significant to management and decision-makers.

2.3. System dynamics

System dynamics is a method for learning about a complex system and the development of management simulation that help to understand system complexities and source of resistance against the policies and designing new effective policies (Otto and Simon, 2008). This methodology is used for discovering and presenting feedback processes and searching for the characteristics of the dynamics of complex systems using level and flow structure, delays, and nonlinear relationships (Mella, 2012; Tegegne et al., 2018). Here, the feedback structure, represented as positive and negative feedback loops, is the main guide of system dynamics that helps interpret the observed dynamic behavior and develop practical hypotheses about these behaviors and structural deficiencies of the model (Asere and Blumberga, 2015; Mella, 2012).

System dynamics methodology has some fundamental differences from other modeling methods. Firstly, it highlights the feedback processes or causal relationships in which the variables affect each other. Secondly, behavioral decision-making is represented in the model, while the decision-makers are assumed to be individuals with limited rationality and incomplete information. Thirdly, it estimates processes with continuous time and consequently can be applied in discovering lag effects. Some software has been developed to build and simulate system dynamics models, of which Vensim is one of the best among them. This software is the framework for conceptualizing, building, simulating, analyzing, optimizing, and developing complex dynamic systems. Vensim has great speed and effectiveness as a tool for simulation analysis.

3. Literature review

There is a lot of research in the literature relating to job satisfaction, the factors that influence that, and the tools used for analysis. For example, Brown and Peterson (1993) identified individual-level demographic and dispositional variables, role perceptions, supervisory behaviors, and job characteristics as influences on employees' Job satisfaction. Generally speaking, tools are necessary to evaluate the level of job satisfaction at each organization. Brayfield and Rothe (1951) proposed the Index of Job Satisfaction, while Smith (1969) suggested IDI. The job Satisfaction Scale was introduced by Arnold and Feldman (1982) and Scholarly Productivity Measure was proposed by Megel et al., (1988). Other tools available in the literature are the Mueller Satisfaction Scale discussed in the Mueller and McCloskey (1990) research. Snarr and Krochalk (1996) introduced Organizational Characteristics Questionnaire as

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another tool for measuring Job satisfaction in healthcare systems. JID is used many times by many researchers for job satisfaction. It is a tool that has attracted the attention of psychological researchers, practitioners, management and academics. JID comprises five dimensions, as listed in the left column of Table 1. They are (i) Work, (ii) Pay, (iii) Opportunities for promotion, (iv) Supervision, and (v) Coworkers. In this paper, we categorize the most critical influenced factor of job satisfaction based on the JDI approach in Table 1.

Table 14. the table of categorized factors based on JDI and literature

JDI Factors	Factors	Researchers	**Influence**
Work (WO)	Job stress	Shader et al., (2001), Fletcher (2001), Tzeng et al., (2002), Yin and Yang (2002), Das and Baby (2014), Davies (2001)	-
	Job security	Nolan et al., (1995), Fletcher (2001)	+
	Hardiness	Larrabee et al., (2003)	+
	Ambiguity	Acorn (1991), Fain (1987)	-
		Chen et al., (2008), Bowling and Hammond (2008)	-
	Conflict	Acorn (1991), Chen et al., (2008), Bowling and Hammond (2008), Acuña et al., (2009)	-
	Working conditions	Nolan et al., (1995)	+
		Adams and Bond (2001), Tzeng et al., (2002)	-
Pay (PA)	Pay(salary)	Holland (1992), Cavanagh and Coffin (1992), Tzeng et al., (2002), Chen et a., (2008)	+
		Plawecki and Plawecki (1976)	+(min)
		Marriner and Craigie (1977)	+(max)
		Fletcher (2001)	-
Opportunities (OP)	Educational level	Lu et al., (2002), Tzeng et al., (2002), Bowling and Hammond (2008)	-
	Promotion	Holland (1992), Yin and Yang (2002), Aiken et al., (2012), Price (2001), Wang (2002)	+
	Autonomy	Lee (1998), Wang and Netemyer (2002)	+-
		Acuña et al., (2009)	+
		Chen et al., (2008)	+
		Bowling and Hammond (2008)	+
Supervision (SU)	Superior (Leadership style)	Kennerly (1989), Shieh et al., (2001), Yin and Yang (2002)	+
		Fletcher (2001), Lutgen-Sandvik et l., (2011), Chen et al., (2008)	-
Coworkers (CW)	Group cohesion	Shader et al., (2001), Adams and Bond (2000), Larrabee et al., (2003), Acuña et al., (2009)	+

(max): strongest factors, (min): weakest factors, + positive, -negative, +-: no significant, (?): Further research needed to determine the correlation of individual factors and JS.

3.1. Problem elaboration and research contribution

The problem of this study is to investigate the dynamic impacts of JS on the quality of service and patient satisfaction. Hence the aims of this research are: (i) to review the literature on the subject matter taking system dynamics modeling into consideration, (ii) to find key factors affecting employees' job satisfaction, and (iii) to identify factors that can be used in determining the quality of service and patients' satisfaction within the health organization. This study contributes to considering all criteria using an integrated model to study the key quality of service criteria within the framework of a multi-criteria structure presented by the stock and flow diagram. The questions of concern are:

(1) How do indigenous and exogenous factors affect each other in a cause-and-effect manner for studying the complexity of the quality of service, job satisfaction and the dynamics of influencing patient satisfaction factors through feedback loops?

(2) What factors affect employees' job satisfaction in the health industry?

(3) What factors affect productivity, income, and financial and nonfinancial coefficients?

Researchers have rarely considered a problem with such vast features. This is a legitimate problem and deserves serious attention, however.

4. Research methodology

The current research includes two main phases. In the first phase, factors are extracted. In the second phase, data is collected.

- Phase I: Factors extraction

1- A deep literature review on the subject matter was conducted to extract key factors.

2- A group of experts were consulted to list the most significant factors affecting job satisfaction. Then, our finding from the literature discussed in 1 was shared with the experts to finalize their opinions.

- Phase II: Data Preparation

3- A questionnaire was distributed among the experts and they were asked to determine how one factor influences another, using + and – signs.

4- This process was completed in two rounds to ensure that experts were highly comfortable with the data provided as requested.

The steps to develop this model are listed below:

Step 1: Using appropriate literature review to identify key factors/variables associated with job satisfaction.

Step 2: Determining system boundary by classifying factors/variables obtained in step 1 into endogenous and exogenous types.

Step 3: Developing causal diagrams using endogenous and exogenous variables.

Step 4: Drawing a stock-and-flow diagram using the causal diagram.

Step 5: Developing a mathematical model of the problem and simulate that with vensim computer software.

Figure 1 depicts the usual steps to be followed and the factors to pay attention to in problem definition, system conceptualization, and simulation and validation stages.

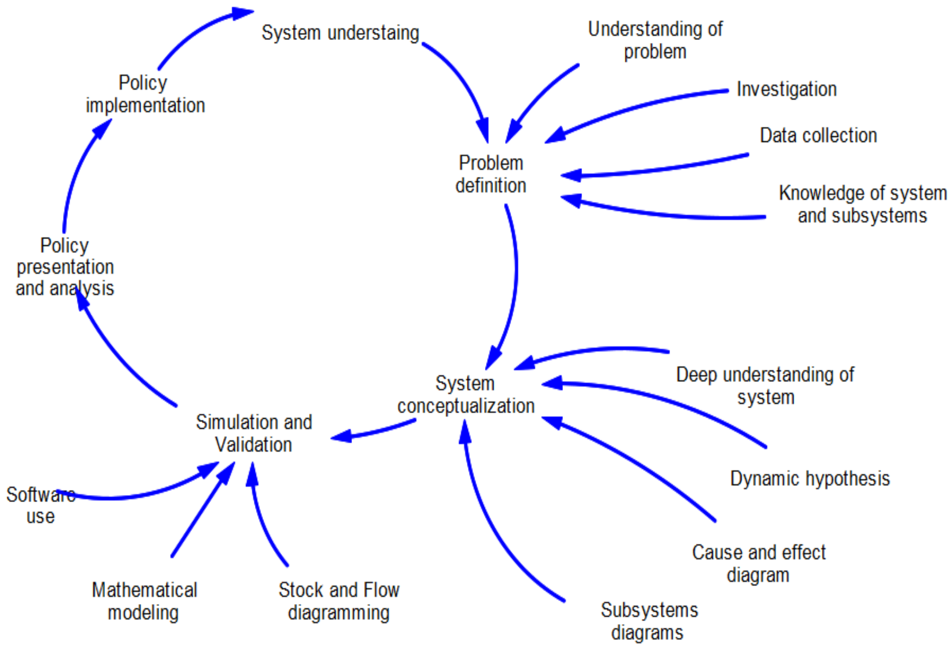

Figure 33. System dynamics steps to solve the problem

5. Dynamic hypothesis

The dynamic hypothesis is a conceptual model that the researcher proposes based on the key variables of the problem. Using main variables, basic reinforcing and balancing loops that are suitable for reasoning and hence knowledge extraction from the expanded model can be drawn. A dynamic hypothesis is an essential tool for being a starting point for model conceptualization. The main benefit of the dynamic hypothesis is that it allows readers to understand the model's complexity better. The dynamic hypothesis of this problem is verbally described below using H1 through H4 signals.

H1: Job satisfaction has positive impacts on quality service and negative impacts on employees' stress

level and absenteeism

H2: Quality service has positive impacts on patient satisfaction

H3: Productivity increases as the stress level in the working environment decreases.

H4: Nonfinancial reward directly impacts the employees' acceptance level of responsibility.

The dynamic hypothesis of the problem under study is depicted in Figure 2 below.

Figure 34. Dynamic hypothesis of the problem

5.1. Factors identification and system's boundary

Because future policies are designed using the influence of independent factors on the dependent ones, it is necessary to consider the affecting factors of job satisfaction. A list of factors affecting job satisfaction was extracted from the literature review and with the help of a questionnaire administered to the experts. In this questionnaire, the following criteria were questioned and assessed regarding affecting or not affecting job satisfaction directly or indirectly. The conceptual relationships between such factors were extracted from the experts' opinions (including specialists in the health and non-health industry).

Table 15. Classification of factors into indigenous and exogenous factors

No.	**Factors**	
1	**Indigenous factors**	Job Satisfaction
2		Perceived results
3		Expectation
4		Financial rewards, Nonfinancial reward
5		Work Pressure
6		Responsibility
7		Income
8		Task conflict
9		Work itself
10		Stress
11		Absenteeism
12		Productivity
13		Quality of service
14		Patient Satisfaction
15		Level of customer
16		Salary
17		Service Cost
18		Employee level
19		Recruitment
20		Dismissal
21	**Exogenous factors**	Culture
22		Supervision
23		Officialism

6. Stock and flow diagram

In system dynamics modeling, three variables convert the casual loop diagram concept into a stock and flow diagram. Level variables are a type of variables that allow accumulation occurs in that. The population of a city is a kind of Level variable because the arrival of a new citizen through birth and immigration to the city causes the population to increase, and when a person dies or is an immigrant from the city, the population level decreases. What does cause the level variable to increase or decrease is known as the rate variable. The following general formula can show the relationship between level and rate variables. Assuming that the level variable is Job Satisfaction, the following formulas can be used for the mathematical modeling of the problem.

$$\text{Job Satisfaction } (t) = \text{Job Satisfaction } (t-1) + DT * \text{Rate } (t-1, t) \quad (1)$$

This means that

$$\text{Rate } (t-1, t) = \text{Changes in Job Satisfaction variable } / DT \quad (2)$$

The third type of variable is known as the auxiliary variable. It is used to describe better the problem, understanding, discussion, modeling and concept analysis. Parameters and constants are allowed to be used in the mathematical modeling of the problem and hence to see their impacts in the simulation results.

7. Dynamic model of problem

The cause and effect diagram demonstrates the system's structure, considering key factors. This diagram is based on the researcher's dynamic hypothesis for the problem. Cause and effect diagrams are a powerful tool for determining the structure of a problem taking entire factors within the boundary of the problem into consideration. Reinforcing and balancing loops are fundamental tools for casual loop diagram. This diagram is used for developing the stock and flow diagram from that. Where it is used for the mathematical model development and hence the simulation.

7.1. Scenario 1 – financial and nonfinancial reward

Figure 3 shows the casual loop diagram for the job satisfaction problem. The relationships between variables are shown by the arrows with the direction starting from the cause factor and ending with the effecting factor. A group of factors build a loop where it starts from one factor and ends at the starting factor eventually after passing once through each factor of the loop. Generating loops are either reinforcing type or balancing type loops. A collection of such interrelated loops built a structure known as a cause and effects diagram. As figure 3 shows, several loops pass through the job satisfaction factor, and hence each has some impact on this key criterion under study here. This diagram consideres the starting point for modeling and simulation, would be used for developing the stock and flow.

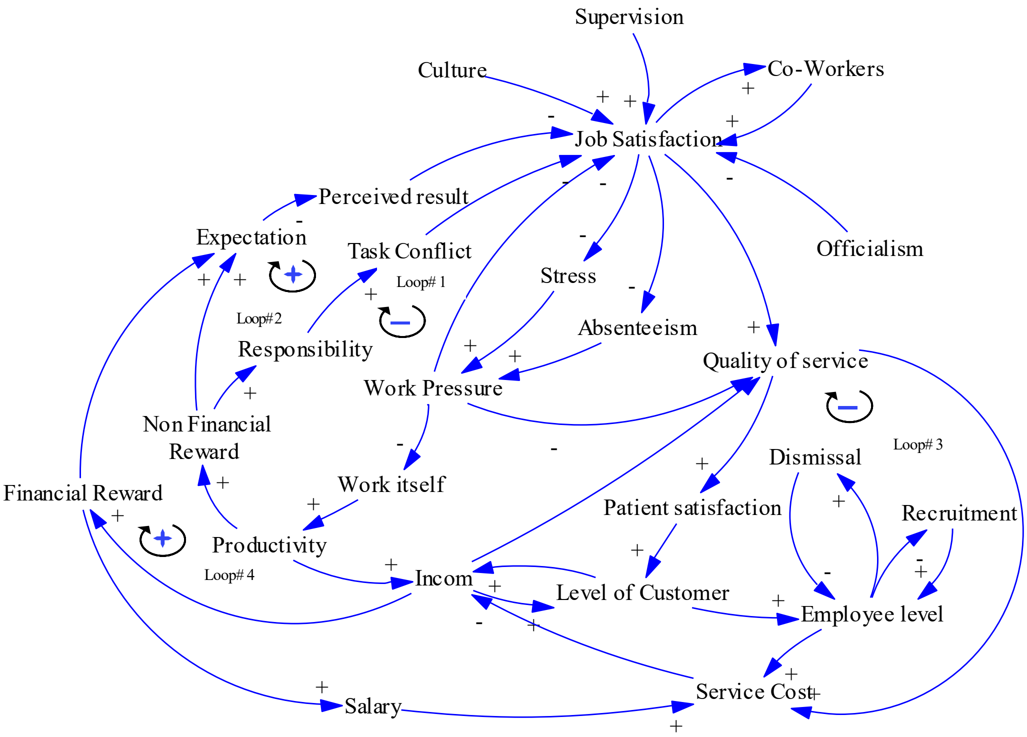

Figure 35. Proposed influence diagram for health care staff job satisfaction.

The causal loop diagram is shown in Figure 3 comprises four loops: loop 1, loop 2, loop 3, and loop 4. Two loops pass through nonfinancial rewards, while the others pass through financial reward factors. Loop 1 passes through factors of job satisfaction, stress, work pressure, work itself, productivity, nonfinancial reward, expectation, perceived results and job satisfaction. As shown, job satisfaction negatively influences job stress and vice versa; in other words, when job satisfaction increases, job stress will decrease, and when job stress increases, job satisfaction will decrease. Job stress positively influences work pressure, which has a counteractive effect on the work itself (workload; scheduling; challenging work; routinization; task requirements) and productivity.

A positive sign produces the multiplication of the signs of arrows (minus or positive, as shown on the arrow). In the current loop (Figure 4), taking the state variable to be job satisfaction, we can expect job satisfaction's trend to be of exponential type, which is the nature of reinforcing loops always. Other factors that positively influence job satisfaction, as shown in Figure 3, are culture, supervision, co-workers and officialism.

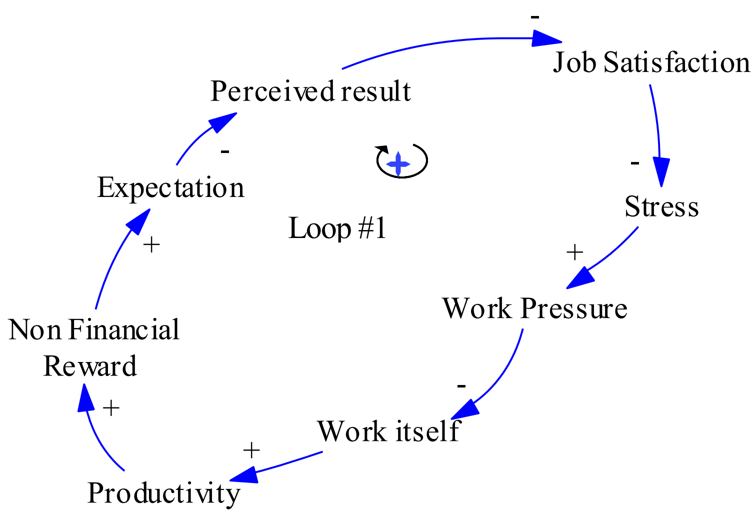

Figure 36. Causal loop diagram of nonfinancial reward (loop1)

7.2. Scenario 2 –financial reward

Scenario one deals with two loops: financial reward and nonfinancial reward as their elements. Now, for scenarios 2 and 3 we consider each sort of reward separately. However, scenario 2 deals with the financial reward only. This means that management is interested in the impacts of financial rewards on job satisfaction.

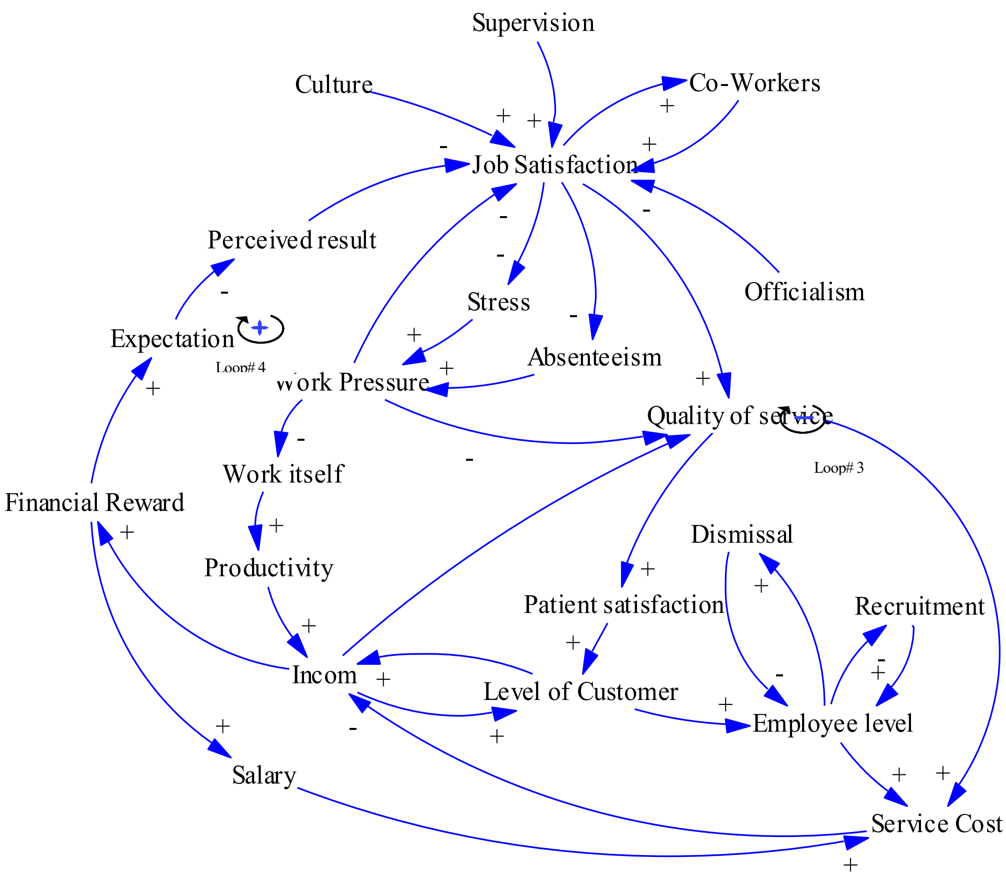

Figure 37. Influence diagram contains financial reward for scenario 2.

As seen from Figure 5, when the income factor increases due to productivity improvement, then financial reward increases. As a result of this phenomenon, expectations increase and hence perceived results decrease. The two most important loops in Figure 5 are loop 3 and loop 4. The overall influence of loop 3 is negative and loop 4 is positive. Therefore, we deal with balancing and reinforcing loops in this model. According to this model, we can analyze all loops and study the effects of any factors, especially financial reward, on job satisfaction.

7.3. Scenario 3 –nonfinancial reward

Many managers believe that nonfinancial rewards work well in many cases to satisfy employees with their job type. For this reason alone, we have proposed this third scenario (See Figure 6). According to the logic proposed in the model below, when productivity increases, nonfinancial reward increases and hence the responsibility and expectation of employees enhances. In loop 1, increasing responsibility causes increasing task conflict and then it causes a decrease in job satisfaction. The overall influence of this loop is negative, while the overall influence of loop 2 is positive.

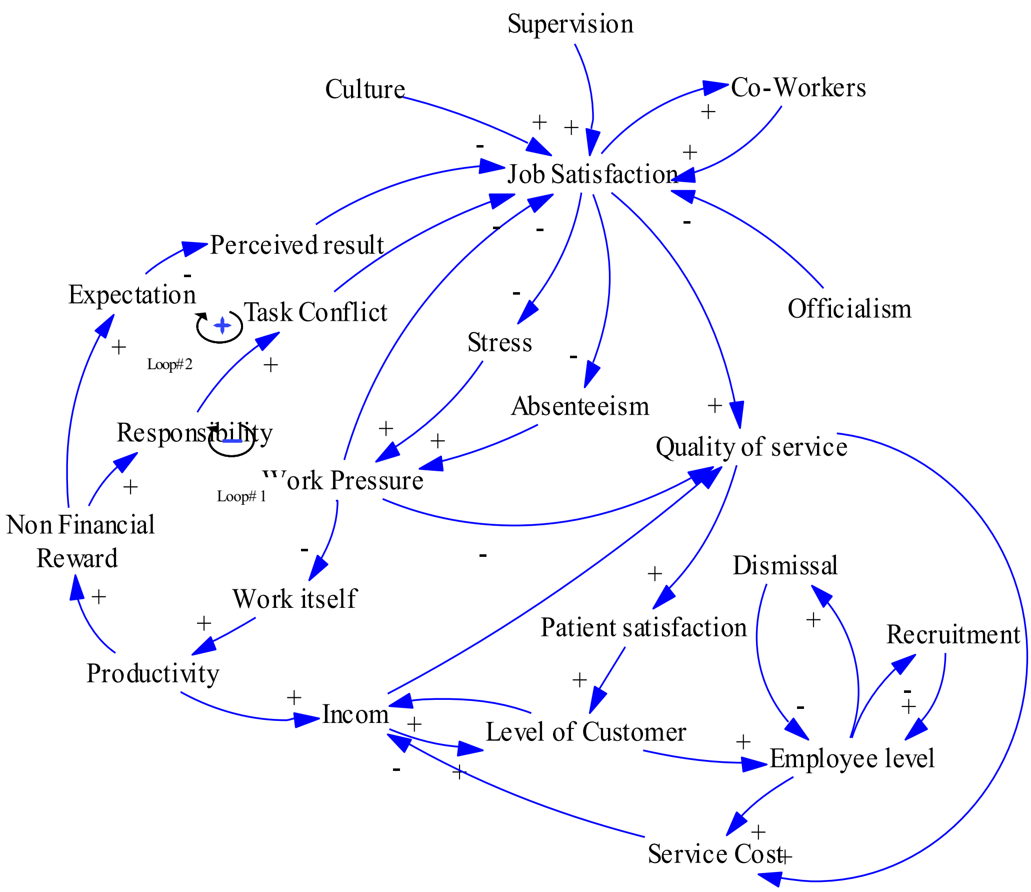

Figure 38. The influence diagram contains a nonfinancial reward for scenario 3

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8. Converting casual loop to flow diagram and running it by VENSIM

According to Figure 1, the fourth model stage is converting the casual loop into the stock-flow diagram. We used VENSIM PLE for this stage. These models are explained below.

8.1. Flow diagram of scenario 1 – financial and nonfinancial reward

The stock and flow diagram for financial and nonfinancial rewards is shown in Figure 7, which is identical in the structure of the job satisfaction and influenced factors. According to Figure 7, three main level-variable are defined: job satisfaction, employee level, and income. Other related factors are defined as rate-variable and auxiliary-variable. Incoming and outgoing rates control job satisfaction, and the initial value is assumed to be 20. The balance equation is defined equation 3 (details of other equations are listed in appendix 1):

Job satisfactin= INTEG (Incoming Rate of JS - Outcoming Rate of JS,20) (3)

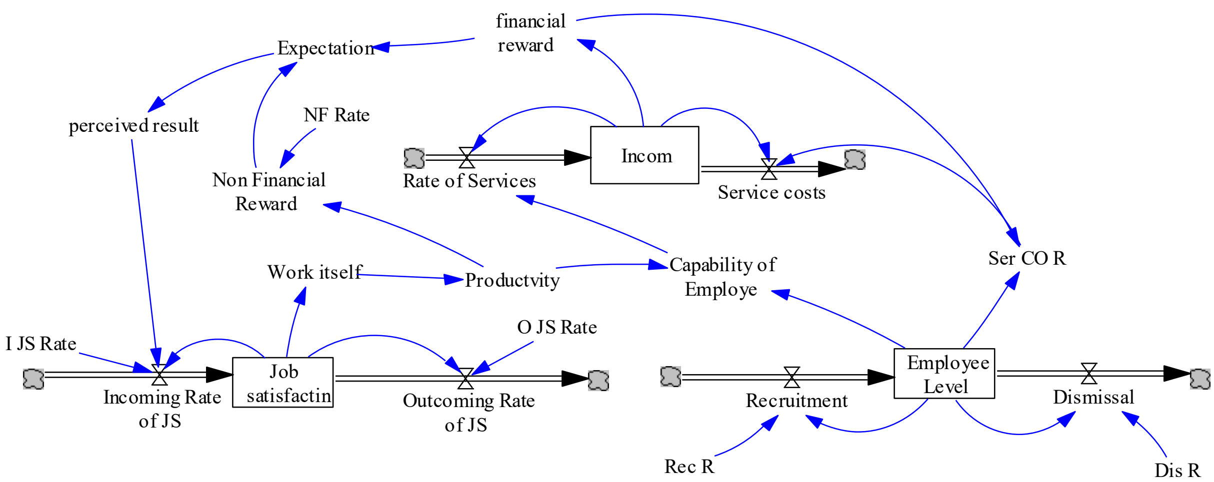

Figure 39. Flow diagram for financial and nonfinancial reward (scenario 1).

The system was first simulated under normal conditions by VENSIM PLE, whereby the final time for the simulation was assumed 100 months. Other equations and assumptions are listed in Appendix 1. The simulated results under normal conditions are shown in Figure 8. The graph shows that job satisfaction and income level changes decrease during the simulation. However, it is observed that using both kinds of rewards (financial and nonfinancial rewards) causes increased job satisfaction and income level. This result is compared with other scenarios in the next sections.

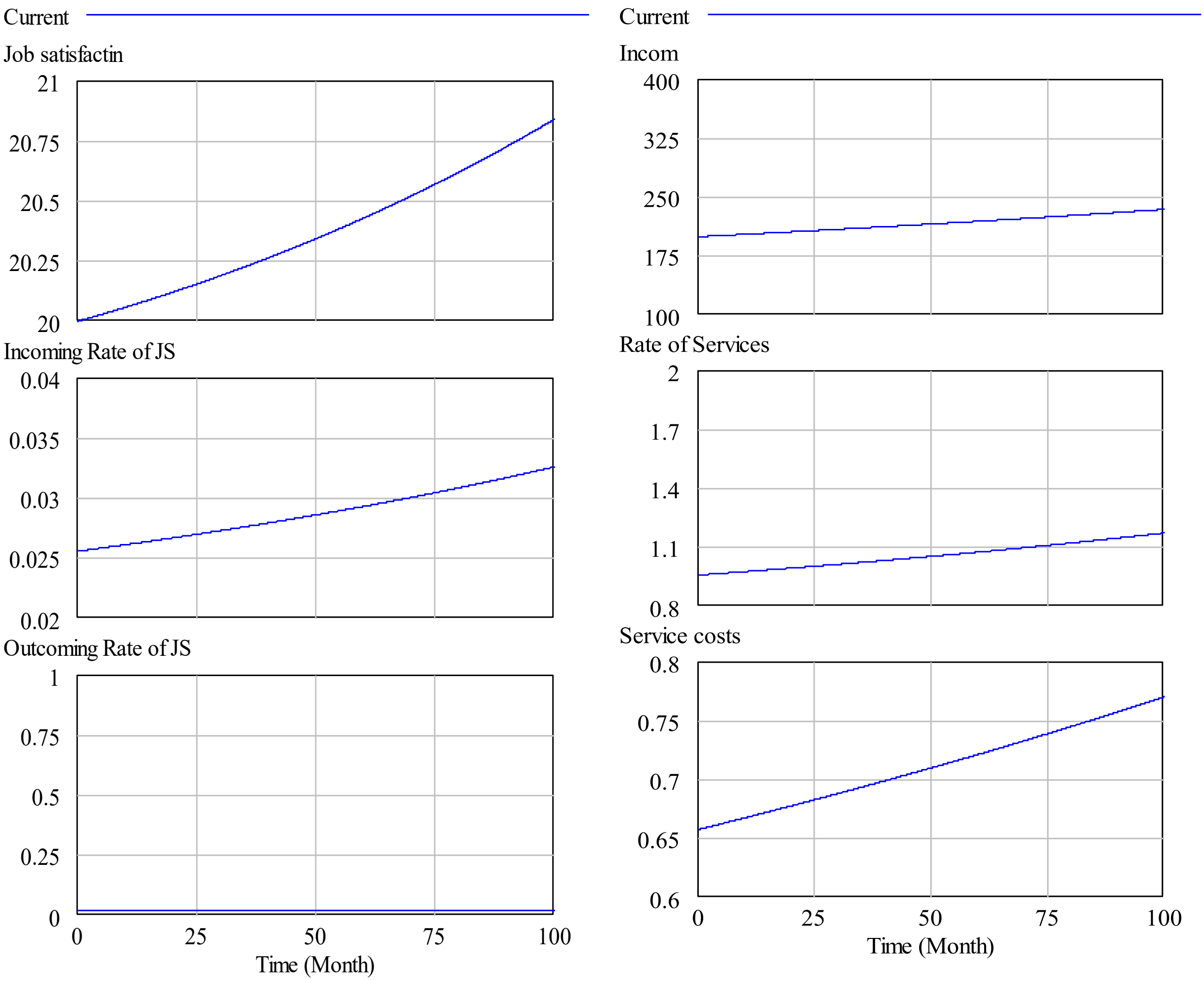

Figure 40. The simulation result of the first scenario.

8.2. Flow diagram of scenario 2 – financial reward

The stock-flow diagram of scenario 2 has been established in Figure 9, which has three main level variables: job satisfaction, income and the number of employees (details of equations are listed in appendix 2). In Figure 9, job conditions and productivity will be improved by increasing job satisfaction. Increasing productivity has a positive effect on the capability of employees, which can increase the rate of services and income level. After increasing the income level, the manager can increase the financial reward. Increasing the financial reward has two crucial effects on the model: increasing expectations and service costs. These two factors prevent the sudden increase in job satisfaction. The results of the simulation model are shown in Figure 10.

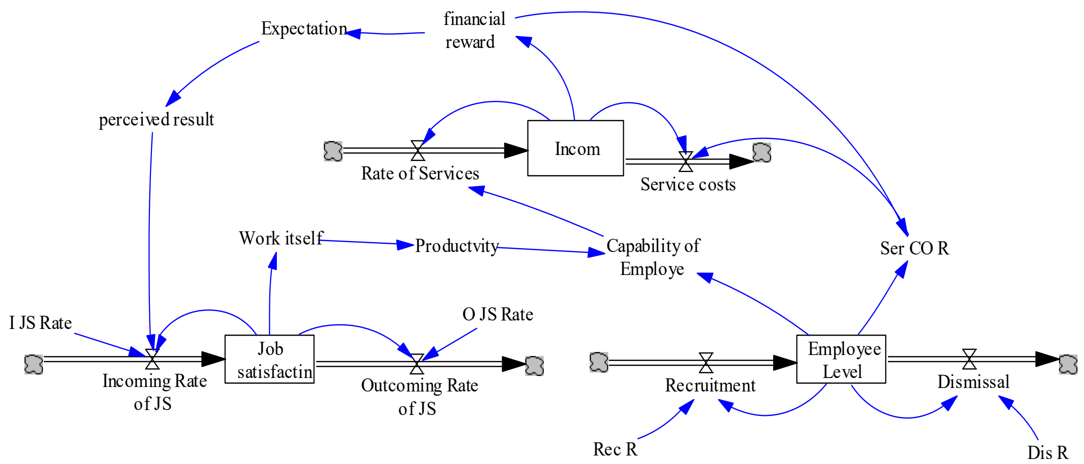

Figure 41. Flow diagram for financial reward (scenario 2).

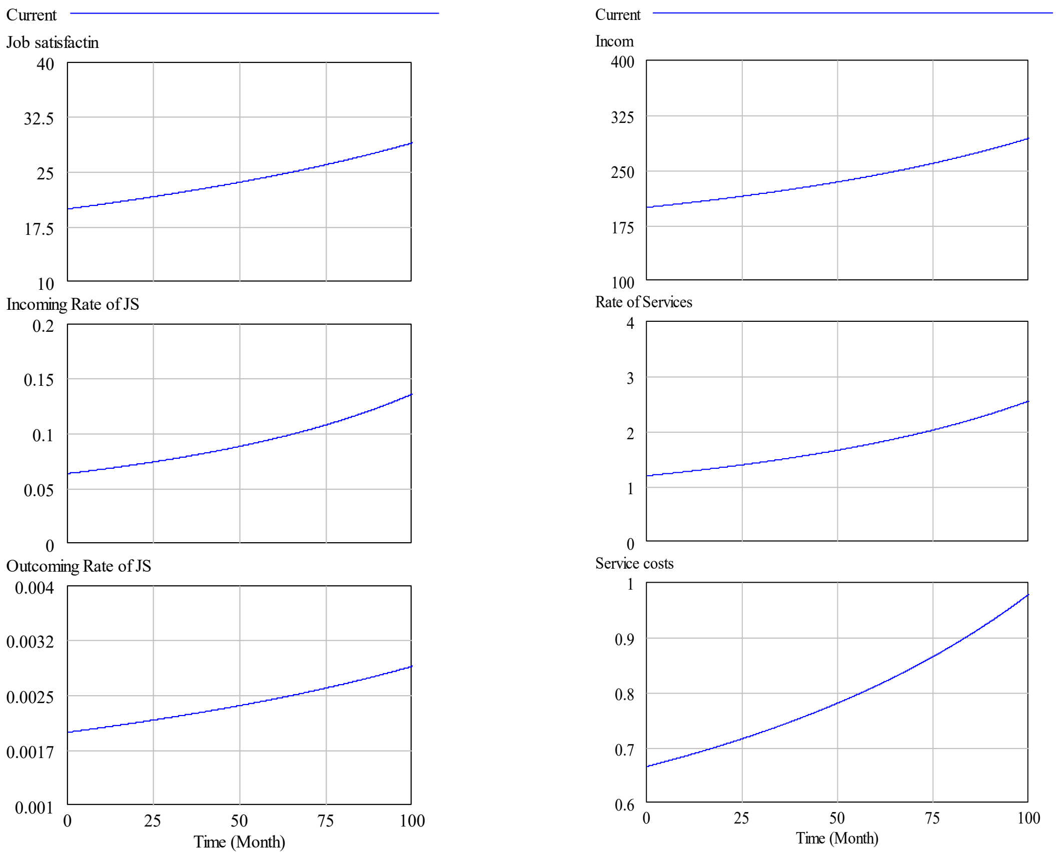

Figure 42. The simulation result of the second scenarios

8.3. Flow Diagram of scenario 3 – nonfinancial reward

For scenario 3, the flow chart model of the three main parts, job satisfaction, income and the number of employees, is used. Figure 11 illustrates a proposed stock-flow diagram, and appendix 3 shows the equation of scenario 3. As it is clear from the diagram, by increasing job satisfaction, the job condition (work itself) will improve, and thus productivity will increase too. Increased productivity will have two significant effects. One is that management will consider nonfinancial rewards to encourage staff. Second, the capability of employees will increase. Increased capability of employees causes increasing in services and consequently improves revenue. Because of more services, increasing the number of employees will be necessary, and therefore the cost of services will increase and the income will reduce.

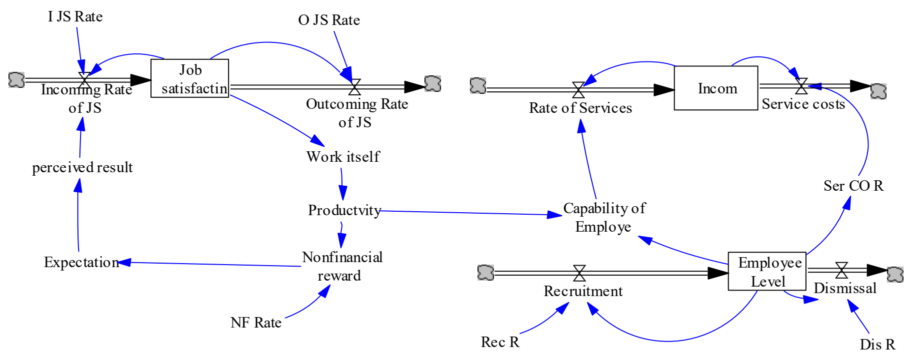

Figure 43. Flow diagram for nonfinancial reward (scenario 3).

Increasing nonfinancial reward causes increasing expectations and thus reduces the perceived result. Therefore, these factors reduce the level of job satisfaction. Using the simulation results shown in Figure 12, we notice that the job satisfaction level will reach a special level after several months and then stay at that level until the simulation period ends.

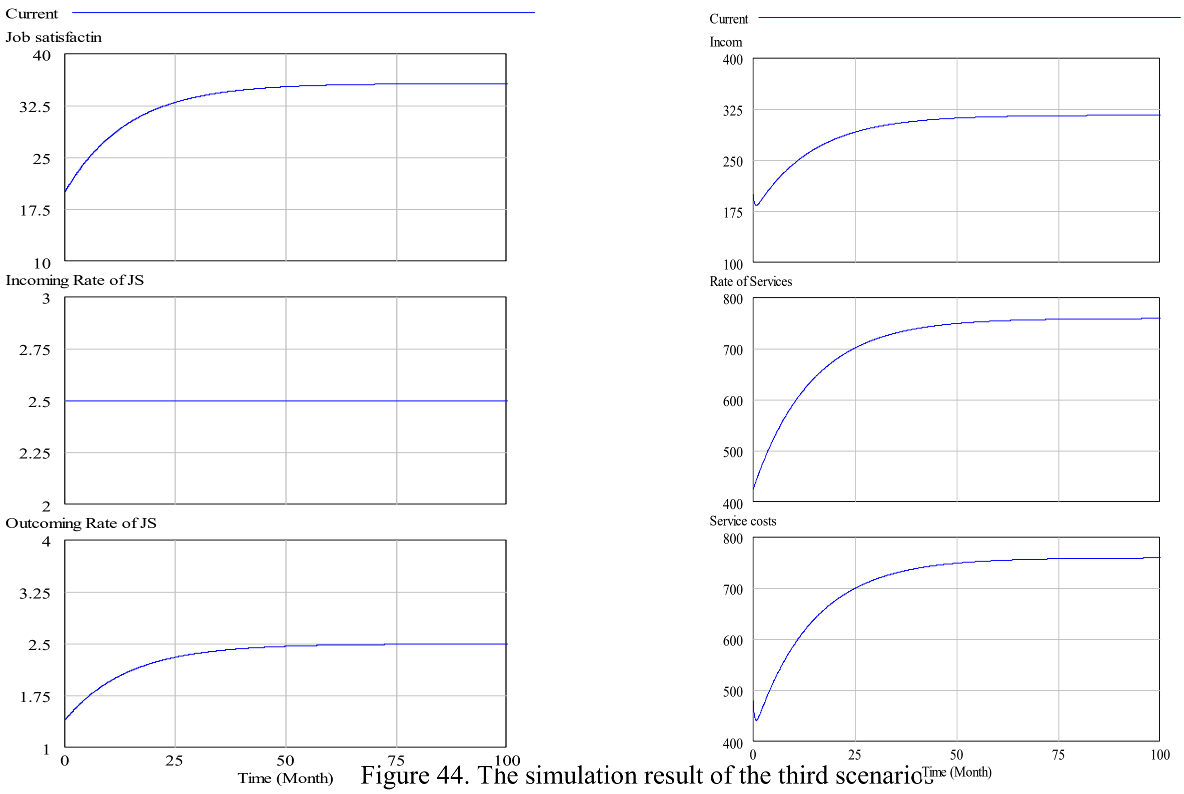

Figure 44. The simulation result of the third scenario.

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9. Conclusion

Determining the factors influencing job satisfaction in service organizations, especially in the health industry, is crucial for managers. Dissatisfaction at the hospital has increased and negatively affects organizations' outputs, such as productivity. Job satisfaction has been identified as a key factor in employee turnover, with the empirical literature suggesting that it is related to a number of organizational, professional and personal variables summarized in Table 2. This study found some crucial factors influencing job satisfaction (Table 2). The second important finding of this paper is the identification of conflict and similarity between factors and effects based on the literature review.

We presented a system dynamics-based model for evaluating job satisfaction in the health industry. The methodology constructs job satisfaction evaluation by analyzing three different scenarios. This model can be used to compare three kinds of rewards in order to analyze the effect of each of them on job satisfaction. The proposed model has been implemented for the employees of a big hospital in Iran. In the previous section, we show the effect of both financial and nonfinancial rewards on job satisfaction. Comparing the three results show that (Figure 7, Figure 9, and Figure 11) using the nonfinancial reward have less effect than the other rewards. The model can further be tailored and used in various health industries. Thus, it may be useful to decision-makers dealing with job satisfaction issues.

This research can be extended in three distinct ways. First, an extension of the proposed model can be used in any industry as well as a rough working environment of the mining industry, to determine the trend of job satisfaction. Second, job satisfaction can be studied in the presence of other forms of rewards given away to employees' families to examine the impacts of that on the satisfaction level. Third, the impacts of joyful organization studied by Moubed & Zare Mehrjerdi (2014) and Zare Mehrjerdi & Moubed (2023) on job satisfaction can also be considered in new modeling.

Disclosure statement

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

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Apendix 1: The details of the first senario equations

1. Capability of Employe=Employee Level*0.2*Productvity
2. Dis R=5e-010
3. Dismissal=Employee Level*Dis R
4. Employee Level= INTEG (Recruitment-Dismissal,300)
5. Expectation=financial reward*Non Financial Reward
6. FINAL TIME = 100 Units: Month. The final time for the simulation.
7. financial reward= 0.02*Incom
8. I JS Rate=0.8
9. Incom= INTEG (Rate of Services-Service costs,200)
10. Incoming Rate of JS=(perceived result)*Job satisfactin*I JS Rate
11. INITIAL TIME = 0 Units: Month. The initial time for the simulation.
12. Job satisfactin= INTEG (Incoming Rate of JS-Outcoming Rate of JS,20)
13. NF Rate=5
14. Non Financial Reward=0.2*Productvity*NF Rate
15. JS Rate=0.001
16. Outcoming Rate of JS=Job satisfactin*O JS Rate
17. perceived result=Expectation
18. Productvity=Work itself*0.01
19. Rate of Services= Incom*0.2*Capability of Employe
20. Rec R=4e-009
21. Recruitment=Employee Level*Rec R
22. SAVEPER = TIME STEP Units: Month. The frequency with which output is stored.
23. Ser CO R=Employee Level+financial reward
24. Service costs=Incom*1/Ser CO R
25. TIME STEP = 0.0625 Units: Month. The time step for the simulation.
26. Work itself=Job satisfactin*0.002

Apendix 2: The details of the second senario equations

1. Capability of Employe=Employee Level*Productvity
2. Dis R=5e-010
3. Dismissal=Employee Level*Dis R
4. Employee Level= INTEG (Recruitment-Dismissal,300)
5. Expectation=financial reward*0.02
6. FINAL TIME = 100 Units: Month . The final time for the simulation.
7. financial reward= 0.001*Incom
8. I JS Rate=0.8
9. Incom= INTEG (Rate of Services-Service costs,200)
10. Incoming Rate of JS=(perceived result)*Job satisfactin*I JS Rate
11. INITIAL TIME = 0 Units: Month. The initial time for the simulation.
12. Job satisfactin= INTEG (Incoming Rate of JS-Outcoming Rate of JS,20)
13. JS Rate=0.0001
14. Outcoming Rate of JS=Job satisfactin*O JS Rate
15. perceived result= expectation
16. Productvity=Work itself*0.001
17. Rate of Services= 0.1*Incom*Capability of Employe
18. Rec R=4e-009
19. Recruitment=Employee Level*Rec R
20. SAVEPER = TIME STEP Units: Month. The frequency with which output is stored.
21. Ser CO R=Employee Level+financial reward
22. Service costs=Incom*1/Ser CO R
23. TIME STEP = 0.0625 Units: Month. The time step for the simulation.
24. Work itself=Job satisfactin*0.01

Appendix 3: The details of the third senario equations.

1. Capability of Employe=Employee Level*Productvity*0.7
2. Dis R=1e-011
3. Dismissal=Employee Level*Dis R
4. Employee Level= INTEG (Recruitment-Dismissal,300)
5. Expectation=Nonfinancial reward*0.02
6. FINAL TIME = 100 Units: Month. The final time for the simulation.
7. I JS Rate=0.1
8. Incom= INTEG (Rate of Services-Service costs,200)
9. Incoming Rate of JS=perceived result*Job satisfactin*I JS Rate
10. INITIAL TIME = 0 Units: Month. The initial time for the simulation.
11. Job satisfactin= INTEG (Incoming Rate of JS-Outcoming Rate of JS,20)
12. NF Rate=20
13. Nonfinancial reward=Productvity*NF Rate
14. JS Rate=0.07
15. Outcoming Rate of JS=Job satisfactin*O JS Rate
16. perceived result= 1/Expectation
17. Productvity=Work itself
18. Rate of Services= Capability of Employe+0.03*Incom
19. Rec R=3e-010
20. Recruitment=Employee Level*Rec R
21. SAVEPER = TIME STEP Units: Month. The frequency with which output is stored.
22. Ser CO R=0.008*Employee Level
23. Service costs=Incom*Ser CO R
24. TIME STEP = 0.0625 Units: Month. The time step for the simulation.
25. Work itself=Job satisfactin*0.1

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